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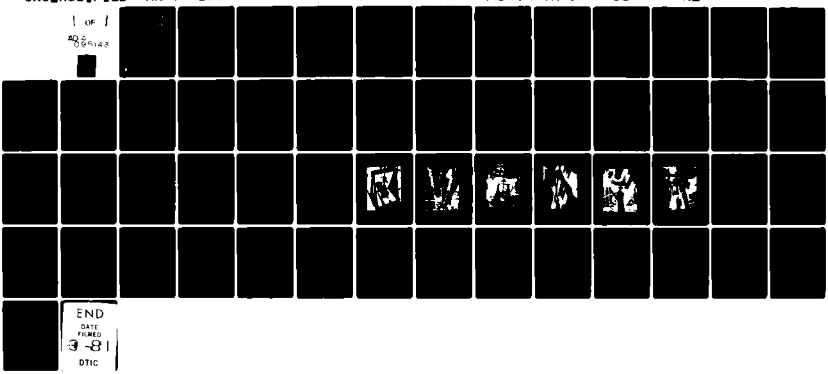

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A COMPUTERIZED BALANCING TECHNIQUE FOR SUPERCRITICAL HELICOPTER SHAFTING

LEVEL II

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Culver City, Calif. 90230

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APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report provides the documentation for a program which demonstrated a method for balancing a full-size supercritical helicopter tail rotor drive shaft using a quasi-static data acquisition technique. The process has been shown to place the center of gravity at all stations within 0.001 inch of the center of rotation. The balancing technique is available for implementation in existing and future tail rotor drive shafts.

Mr. Albert E. Easterling of the Propulsion Technical Area, Aeronautical Technical Division and Mr. Fred Reed of the Directorate for Systems Engineering and Development, US Army Aviation and Research Development Command served as project engineers for this effort.

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Ultrasonic Gaging	Drive Shaft
One Pass Balancing	Rotor
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A full-size supercritical helicopter tail rotor drive shaft has been balanced using a quasi-static data acquisition technique. The method employs ultrasonic gaging equipment and a digital computer to determine the amount and location of the balance correction. In one 15-minute pass, the system has demonstrated the ability to locate the center of gravity (CG) of the shaft within 0.001 inch. The balanced shaft has run at speeds up to 10,500 rpm,

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including sustained operation at four critical speeds, with acceptable vibration at critical speeds. Operation at the design speed (between 2nd and 3rd critical speed) was well within standard high quality balance values.

SUMMARY

This report presents the results of a balancing technique for flexible rotors. The technique was demonstrated using the YAH-64 Phase I Helicopter Tail Rotor Drive Shaft as the flexible rotor.

The technique measures the mass distribution of the rotor about its center of rotation at a series of stations along its length. It uses ultrasonic gaging equipment, a digital computer to process the 50,000 data points measured by the equipment, and printout to define the localized balance needed to bring the local center of gravity back to the center of rotation. The process has been shown to place the center of gravity at all stations within 0.001 inch of the center of rotation.

PREFACE

This report was prepared by Hughes Helicopters, Division of Summa Corporation, under Contract No. DAAK51-78-C-0021, funded by Applied Technology Laboratory, USAAVRADCOM, Fort Eustis, Virginia. It covers the work performed during the period September 1978 to February 1980 and is the final technical report summarizing the activity. The contract statement of work breaks down the activities into six tasks.

TASK I

A search was made for manufacturers of ultrasonic gaging equipment. Three companies were contacted for literature. All responded, but only one (N.D.T. Instruments) was able to deliver hardware. It was concluded that the ability to obtain the measuring requirements for this program using ultrasonics was "state of the art".

TASK II

Design and fabricate the equipment required to modify an existing Hughes Helicopters' balancing fixture (used during the Phase I development of the YAH-64 Helicopter), for compatibility with the automatic data acquisition system and interface with the computer. Create the computer programs required to perform the calibration, acquisition, and data functions analysis. The final product is a plot and tabulation of the necessary balance corrections.

TASK III

Select two shafts that were manufactured during the Phase I development of the YAH-64 Helicopter Program. The two shafts (P/N 7-113500003) were S/N-1U, used in the Phase I YAH-64 ground test vehicle, and S/N-5U, a spare for air vehicles 02 and 03.

TASK IV

Trial balance S/N-1U for checkout and evaluation.

Balance S/N-5U witness by the Contracting Officer's representative.

TASK V

Conduct an economic analysis of this method for balancing 1,000 shafts.

TASK VI

Present a Government/industry briefing at Hughes Helicopters' facility, Culver City, California.

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INTRODUCTION

As designers become more weight and vibration conscious for new aircraft designs, the introduction of power-transmitting shafts that run at supercritical speed becomes increasingly attractive. Balancing such high-speed shafts so that they run smoothly has long been a problem, with the process being both difficult and costly. It traditionally requires many trial runs over the rpm spectrum to achieve good balance.

The technique described in this report was developed by Hughes Helicopters (HH) and has been granted U. S. Patent No. 4, 170, 896 dated October 16, 1979. The balance method requires no trial runs to develop baseline data. All required data is obtained during a "one shot" pass along the slowly rotating shaft, is automatically processed, and the operator is given a graphic display of how much balance is to be applied along the shaft. The system is shown schematically in Figure 1.

Figure 2 is a schematic representation of the balancing process. The ultrasonic transducer and sensors ride along a track that is parallel to the shaft's centerline of rotation and measure two quantities at each of 250 azimuthal locations around the shaft for each lengthwise station along the shaft. The "slave" sensor measures the distance from the transducer to the outside surface of the shaft while the "master" measures the thickness of the wall of the shaft. The computer integrates this information around the periphery of the shaft, calculates the local center of gravity, calculates the amount and location of balancing tape needed to bring the local center of gravity and center of rotation into coincidence, and displays the balance requirements in both analog and digital form. The operator then applies the adhesive-backed aluminum tape to the surface of the shaft.

This method is valuable not only as a shaft-balancing procedure but also as a low-cost receiving inspection tool to qualify the basic tube for the important parameters which make an acceptable supercritical drive shaft, i.e., straightness, wall thickness variations, and dents. By rejecting tubes that require large or impractical balance adjustments, all the labor of shaft manufacture is saved, thereby minimizing the rejection rates for a finished shaft.

INSTRUMENTATION

The instrumentation required to conduct this program can be categorized into five basic areas:

- Ultrasonic gaging
- Preamplification
- Analog-to-digital conversion
- Shaft azimuth encoding
- Digital computation and output

ULTRASONIC GAGING

The ultrasonic equipment was purchased from N. D. T. Instruments, Inc., Huntington Beach, California. It consists of two specially prepared Nova Scope 2000 instruments and one ultrasonic transducer with a water coupling adapter and a mechanical manipulator. One of the instruments acts as a slave, while the other performs as the master.

The master unit provides the excitation pulse to the transducer, and both Nova Scopes read back the ultrasonic signal response. The slave unit is calibrated to provide data on the "water path" or distance from the transducer to the top surface of the specimen (drive shaft surface). The master is set up and calibrated to provide the wall thickness data.

Both pieces of data are extracted simultaneously from the same ultrasonic pulse. Figure 3 shows a typical ultrasonic pulse and the interpretation of the peaks. The slave signal circuitry employs a blocking gate to delay the timing circuit. This gate is set up by the operator to some short time before the first echo. The purpose is to avoid false readings due to environmental noise. The time between the main pulse and the first return echo is equated to twice the distance to the first surface being measured. The instrument is calibrated by making precise known changes in the distance to the first surface, and adjusting the gain and zeroing potentiometers on the front of the Nova Scope. The digital display on the front of the Nova Scope provides a convenient indication for calibration and can be used at any time to indicate the parameter being gaged.

The master unit circuitry is set up to block out the main pulse and measure the time from the first return echo to the second return echo. This time is equated to the wall thickness. This unit is calibrated by using several known thicknesses of aluminum and adjusting the gain and zero potentiometers until the digital display indicates the thickness of the sample being gaged. An electrical connection to an analog voltage that is proportional to the digital signal displayed on the front is provided at the rear of each Nova Scope 2000. This analog voltage is the input to the computer.

PREAMPLIFIERS

Standard DC laboratory instrumentation amplifiers serve as preamplifiers between the analog output of the Nova Scopes and the analog-to-digital (A/D) converters of the computer to produce a digital resolution at the computer compatible with the desired sensitivities; i.e., less than 0.001 inch for eccentricity measurement and 0.0001 inch for the wall thickness measurement.

DIGITAL COMPUTER A/D

A Hughes Helicopters' laboratory computer is used for this program. It is a Hewlett Packard 1000 computer with a HP 2313 Data Acquisition System for multiplexing, A/D, timing, and control. The multiplexer is capable of data rates in excess of 40,000 readings per second. The azimuth error due to multiplexing 250 readings per revolution on three channels is 0.00675 degree, 2
which is considered nil. B

SHAFT AZIMUTH ENCODING

The data recording for this program needs to be referred back to a physical location on the drive shaft. This requirement is satisfied by the fabrication of a special Hughes Helicopters developed electronic circuit that encodes the shaft into 250 equally spaced segments around its azimuth. The use of 250 units is an arbitrary but convenient buffer size in the digital computer.

The encoding system consists of an aluminum disc approximately 8 inches in diameter and 0.065 inch thick. The disc is machined to provide 250 equally spaced radial cuts 0.020 inch wide and 0.25 inch deep from the outside diameter. One of the cuts (the master) is 0.50 inch deep. A pair of infrared optical encoders are used to start and stop a pulse circuit. As the master slot in the timing plate passes the optical encoder, an automatic circuit is enabled, providing the computer with a trigger at each of 250 equally spaced azimuth locations. The automatic trigger circuit is disabled after one complete revolution, and no additional readings can be taken until the reset switch is activated. Figure 15 shows the encoding disc and the operator control switch.

At each trigger, the computer scans the required data channels, stores the information, and waits for the next trigger. Appendix A provides a complete explanation and schematic of this system.

DIGITAL COMPUTER

The HP 1000 digital computer is programmed to do the following tasks:

a. Calibrate the incoming voltages and convert the readings into engineering units.

b. Read the data during a measurement run, place it into an array in memory, and print the results on a line printer after each azimuth scan (1 per station for 100 stations).

c. Graph the results of a complete run on a plotter and print the required balance corrections in tabular form on a line printer.

Appendix B provides listings and explanations of all programs used for this project. Programs are written in both BASIC and FORTRAN. BASIC is used when speed is not a factor, while FORTRAN is needed to take data and perform the computations quickly.

SYSTEM CALIBRATION/RESOLUTION

The initial run of this system was checked against known inputs for reliability, repeatability, and accuracy. The first check assured that the voltages read at the analog output of the Nova Scope were being recorded by the computer. This check verified that magnitude, polarity, and channel designation were correct.

The second check verified that all the program logic and math algorithms functioned as expected.

The third check measured the wall thickness and eccentricity of a calibration tube (Figure 11) made specifically for this program. This tube was measured with micrometers to determine, by a separate method, the same parameters that the ultrasonic system does.

A fourth check was to run the system on the first drive shaft specimen, S/N-1U, and keep the transducer at the same position for all 100 station points.

This test proved system resolution to be less than 0.001 inch and 2 degrees for locating the centroid. The results of this test are plotted in Figure 4. In an ideal system, this check would show all data to be exactly the same.

PROCEDURE AND RESULTS

Two Phase 1 AAH shafts (4.5" O.D. by 17 feet long) were balanced to demonstrate the technique. The first, S/N-1U, was used during Phase I development of the YAH-64 in the ground test vehicle and was not flightworthy because of some slight damage near one end, caused by rubbing on a frame. The damage is slight, a photograph would not show it, and the effect on the balance process is considered nil.

All balance material on the shaft was removed. The shaft was cleaned of all dirt or flakes of paint or epoxy that might cause an ultrasonic artifact and the shaft was installed in the spin fixture for the ultrasonic data scan. The first scan took 15 minutes, and produced a plot and tabulated correction weight chart within two minutes. The scan time is documented by the data acquisition rate of 8 seconds per station.

A laboratory technician was instructed in how to read the plotted and tabulated data. This instruction required approximately 30 minutes.

The hand lay-up of the aluminum balance tape used as the correction medium required 3.5 hours. The correction process is accomplished in two phases:

a. Lay out, using a suitable marker, the azimuth locations (station 1 to station 100). This process was responsible for over 1.5 hours of the balancing time.

b. Apply the tape in layers and lengths at the required azimuth, starting with the widest tape and working up to the narrowest.

The initial balance was not good enough, and upon investigation it was discovered that all computer corrections were based on 0.005-inch-thick aluminum tape, while the tape being used was 0.003 inch thick. A subsequent run of the same data with a new constant for the 0.003-inch-thick-tape provided new data. A new taping operation was done in a 1.5-hour per period.

The operation of the shaft through four critical speeds (0-175 Hz) was successful, with success being determined by dwelling at the critical speeds for several minutes with no damper smoking or evidence of excessive heating. Figure 12 illustrates the shaft and mounting features.

The results of S/N-5U were similar to S/N-1U except only one taping was required.

The adhesive quality of the aluminum tape used in this demonstration was great enough to guarantee adherence to 5 times the maximum operational rpm of the YAH-64 tail rotor drive shaft. To keep the adhesive safe from environmental factors, a moisture-resistant sealant must be painted over the tape and especially along its edges. The density of the cured epoxy sealant is 0.47 lb/cu. in., and has been found to have little or no effect on the balance when used in the quantities required here.

Table 1 presents results of measured lateral response at the aft end of the shaft bearing mount. Data was recorded as velocity and converted to displacement and acceleration by analysis. This table is presented to show, quantitatively, the dynamic response characteristics of the drive shaft as mounted in the spin fixture. Comparisons to response characteristics when used in another environment, such as an A/C, may show significant differences due to the dynamics of the new structure attached.

Table 2 and Figures 5 and 6 are computer generated charts and graphs of S/N 1U and 5U showing mass distribution measurements recorded, and the required corrections. Figures 7 and 8 are spectrum analysis plots of before and after balance corrections on S/N 5U. Figures 9 and 10 are spectrum analysis plots after correction runs on S/N 5U. These figures show the pertinent vibratory response characteristics measured during these tests and are the source of the data presented in Table 1. The effect of the balancing process is clearly shown by comparison of the magnitudes of the various plots.

TABLE 1. VIBRATION CHARACTERISTICS - S/N-5U

Frequency (Hz)	Voltage* (rms)	Velocity (in/sec)	Displacement (Inches Peak-to-Peak)	Acceleration (g's)
13	0.042	0.074	0.0018	0.016
50	0.142	0.741	0.0047	0.603
81**	0.0035	0.006	0.000024	0.008
106	0.110	0.194	0.0006	0.334
175	0.110	0.194	0.0004	0.550

*Voltage to engineering units = 0.00176 in/sec rms/mv rms
**Operational speed of driveshaft in YAH-64

TABLE 2. DIGITAL BALANCE PRINTOUT – S/N 5U

DATE: FEBRUARY 6, 1980 TIME: 5: 8 PM S/N 5U

DATE: FEBRUARY 6, 1980 TIME: 5:19 PM

Station	1 inch	1/2 inch	1/4 inch tape	Angle (Degrees)
1	1	0	0	192
2	1	0	0	189
3	1	0	0	193
4	1	0	0	191
5	1	0	0	171
6	0	1	1	191
7	1	0	0	212
8	1	0	0	190
9	0	1	0	170
10	0	1	0	144
11	0	1	1	133
12	0	1	1	148
13	0	1	1	149
14	0	0	1	121
15	0	0	1	62
16	0	1	0	[illegible]
17	0	1	0	56
18	0	1	1	87
19	0	1	1	[illegible]
20	0	1	0	[illegible]
21	0	1	1	54
22	0	1	1	[illegible]
23	1	0	0	[illegible]
24	1	0	0	54
25	0	1	1	[illegible]
26	0	1	1	[illegible]
27	0	1	0	[illegible]
28	0	1	1	[illegible]
29	1	0	[illegible]	[illegible]
30	1	0	1	[illegible]
31	1	0	1	[illegible]
32	1	0	1	60
33	1	0	1	[illegible]
34	1	1	1	[illegible]
35	2	0	1	[illegible]
36	1	0	1	[illegible]
37	1	1	1	[illegible]
38	1	1	1	[illegible]
39	2	0	0	[illegible]
40	2	0	0	69
41	2	0	0	[illegible]
42	1	1	[illegible]	[illegible]
43	2	0	0	80
44	2	0	0	81
45	2	0	0	87

TABLE 2. DIGITAL BALANCE PRINTOUT – S/N 5U (CONT)

Station	1 Inch	1/2 Inch	1/4 Inch [illegible]	[illegible]
46	[illegible]	0	1	95
47	[illegible]	0	0	83
48	[illegible]	0	1	87
49	[illegible]	0	1	77
50	[illegible]	0	1	82
51	[illegible]	0	1	83
52	[illegible]	0	0	87
53	[illegible]	0	0	85
54	[illegible]	0	1	87
55	[illegible]	1	1	83
56	[illegible]	1	0	94
57	[illegible]	0	1	99
58	[illegible]	0	0	102
59	[illegible]	0	1	98
60	[illegible]	1	0	92
61	[illegible]	1	0	77
62	[illegible]	1	1	79
63	[illegible]	0	0	84
64	[illegible]	1	1	88
65	[illegible]	1	0	95
66	[illegible]	1	1	97
67	[illegible]	1	0	93
[illegible]	[illegible]	1	1	88
[illegible]	[illegible]	1	0	88
70	[illegible]	0	1	88
71	[illegible]	0	0	88
[illegible]	[illegible]	0	0	[illegible]
[illegible]	[illegible]	0	1	92
74	[illegible]	1	1	92
[illegible]	[illegible]	1	1	93
[illegible]	[illegible]	0	0	100
[illegible]	[illegible]	[illegible]	[illegible]	98
[illegible]	[illegible]	[illegible]	[illegible]	93
[illegible]	[illegible]	[illegible]	0	99
[illegible]	[illegible]	1	0	108
[illegible]	[illegible]	1	0	103
[illegible]	[illegible]	1	0	103
[illegible]	[illegible]	1	0	109
[illegible]	[illegible]	1	0	116
[illegible]	[illegible]	1	1	118
[illegible]	[illegible]	1	0	123
[illegible]	[illegible]	0	1	122
[illegible]	[illegible]	0	0	122
[illegible]	[illegible]	1	0	134
[illegible]	[illegible]	1	0	116
91	[illegible]	[illegible]	1	113
[illegible]	[illegible]	[illegible]	1	107
[illegible]	[illegible]	[illegible]	0	97
94	[illegible]	[illegible]	0	94
95	1	1	1	123
[illegible]	[illegible]	0	0	117
[illegible]	[illegible]	[illegible]	0	109
[illegible]	[illegible]	[illegible]	0	111
[illegible]	[illegible]	1	0	110
100	[illegible]	1	0	110

ECONOMIC ANALYSIS

A cost effectiveness analysis was conducted to determine the impact of using this method of balancing the YAH-64 supercritical tail rotor drive shafts.

The cost to install the system, including computer and programming time, is estimated at $51,500. The estimate is in 1980 dollars and is based on the following equipment.

Manufacturer	Model	Name	Cost
HP	9825A	Desk Top Computer	$12,000
HP	3437A	System Voltmeter	2,000
HP	Typical	Printer Plotter	5,000
HP	HP-IB	Interface Card	500
HP	A/R	I/O Roms	1,000
HP	3439A	Scanner	2,000
NDT	2000	Nova Scope	18,000
		Software Development	10,000
			$51,500

The cost of this equipment, amortized over 1,000 parts, is $51.50 each. The cost could be reduced considerably if the operation were installed at a facility that could time-share a computer. The actual C.P.U. time required to do this job is very short; however, during the data scan at a given station, the computer must devote continuous time to data acquisition.

The minimum equipment required is the ultrasonic system, the software, a high speed multiplexer, and the A/D converter. It is estimated that this minimum system could be installed for approximately $35,000.

The time to actually balance a shaft can be divided into two areas: data acquisition and balance correction. The data acquisition and printout has been demonstrated to take less than 15 minutes. The balance correction has been demonstrated to take approximately 3 hours. These are actual documented times from the work done on this program; however, improvements of at least 2:1 can be realized under production conditions.

For comparison, the time to balance the YAH-64 tail rotor drive shaft using current technology is documented in program records at 8 hours per shaft.

Based on 1000 shafts, the labor saved is at least 3.75 hours per shaft. Assuming the value of labor through G & A to be $30.00 per hour, this represents a total labor savings of $112.50 per shaft, or $112,500.00 for 1000 shafts.

The YAH-64 uses two supercritical and two subcritical shafts to which this process could be applied. Since four shafts per A/C represent four times as much balancing labor, as mentioned above, the costs for balancing 1000 shipsets of Tail Rotor Drive Shafts could be reduced approximately $450,000.00, using this method.

CONCLUSIONS

It can be concluded after reviewing the data generated during this program that:

a. The method described and demonstrated herein does locate the center of gravity of the shaft on the center of rotation, and it constitutes a condition of balance which is not changed by rotational speed.

b. The degree of balance required is dependent on the desired operational speed of the end use of the shaft.

c. A shaft designed to operate supercritically can be balanced by making one quasi-static data run. There is no requirement for high speed spin runs.

RECOMMENDATIONS

It is recommended that a study be conducted to determine the practical limitations of shaft interchangeability. Although a shaft can be balanced to locate its center of gravity within 0.001 inch of the center rotation, in a balance machine, the balance is only as good as the location of the center of gravity in its final use. This should be done during the original design of the shaft application, so that balance operations can be done on a bench set up during manufacture. The eccentricity of all mating rotating parts in the end application can sum to a significant unbalance which can only be accounted for in an in-place balance.

This program has highlighted the value of this technique as a receiving inspection tool, as well as a balancing technique. It is also recommended that this system be considered as a method of determining the acceptability of any tubular materials which are used in applications where straightness and wall thickness uniformity are essential.

Further development is recommended to extend the automation process, first to a computer-driven printer that locates the centerline of the balance tape along the drive shaft, and in a second step to develop an automatic tape-laying mechanism.

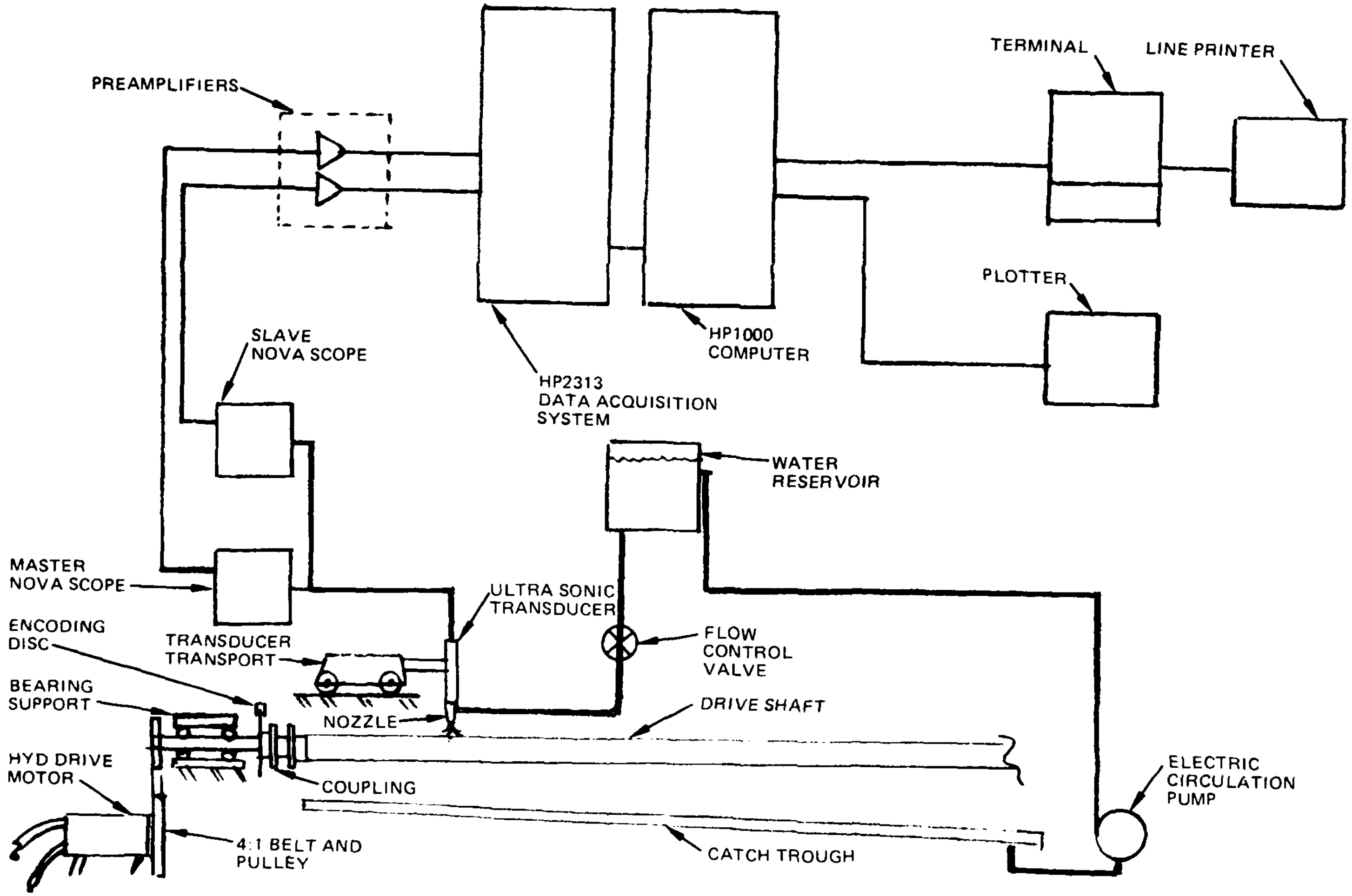

Figure 1. Schematic of balancing system.

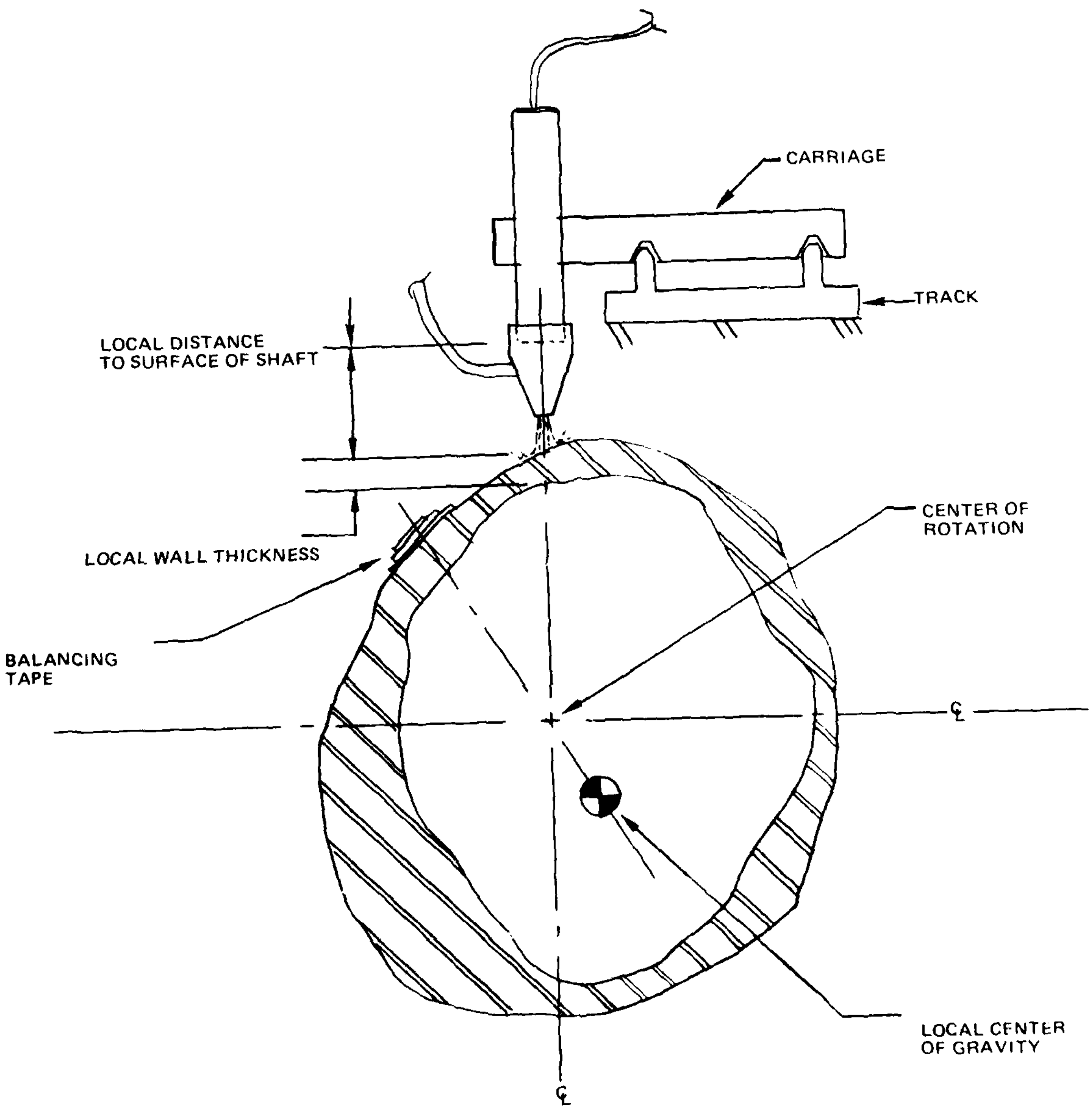

Figure 2. Schematic of balancing process.

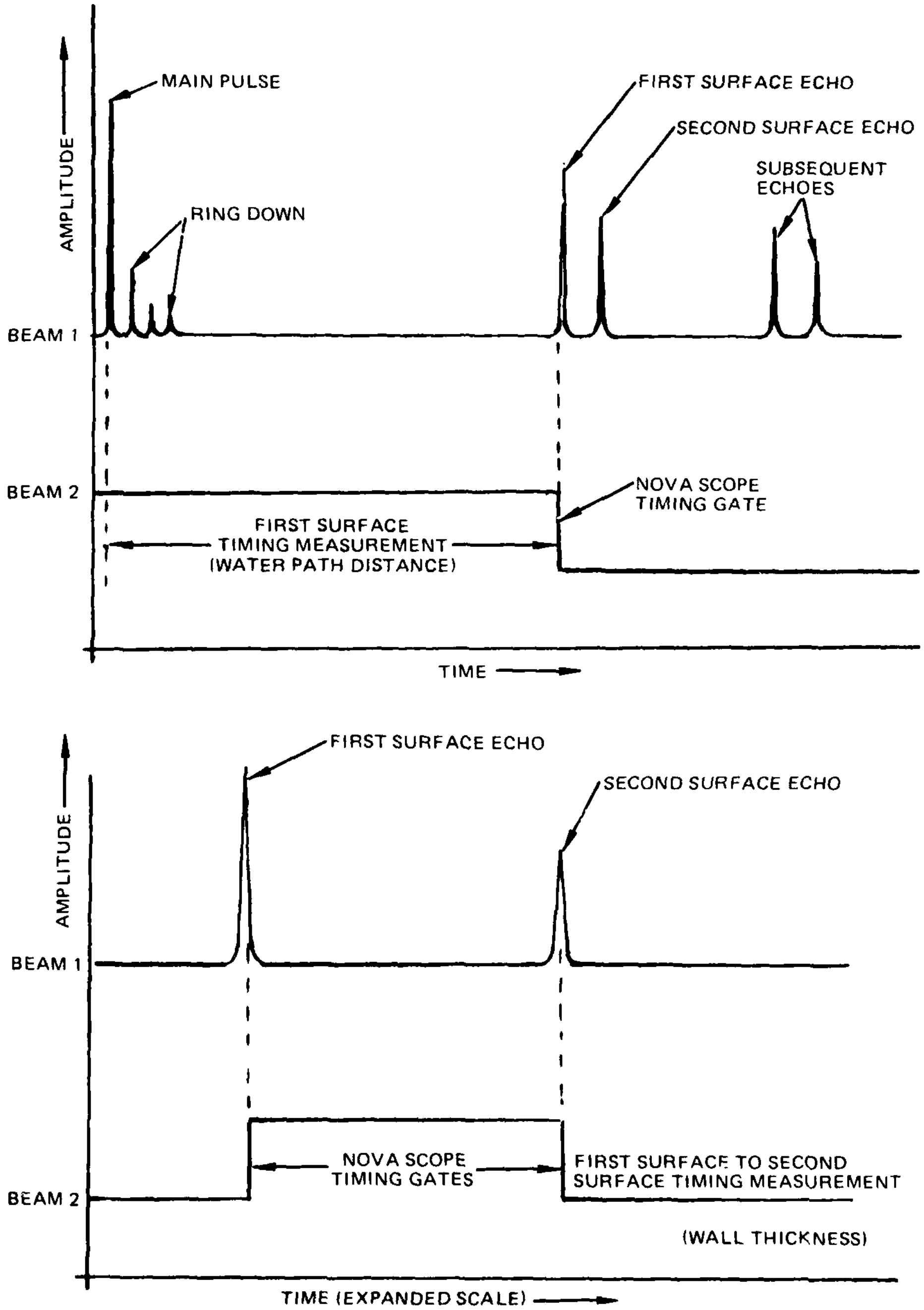

Figure 3. Ultrasonic signal.

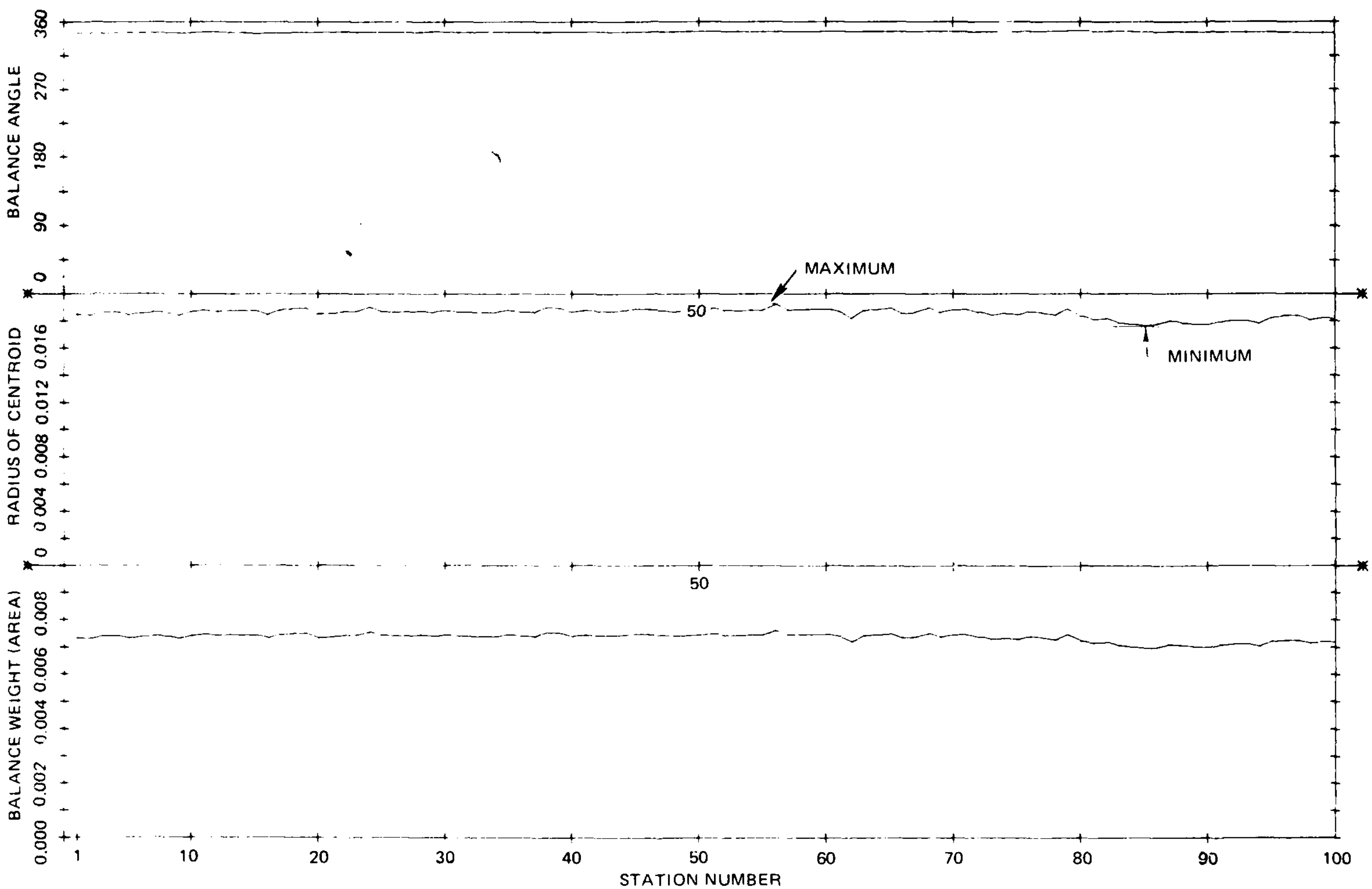

Figure 4. Computer plot of system calibration.

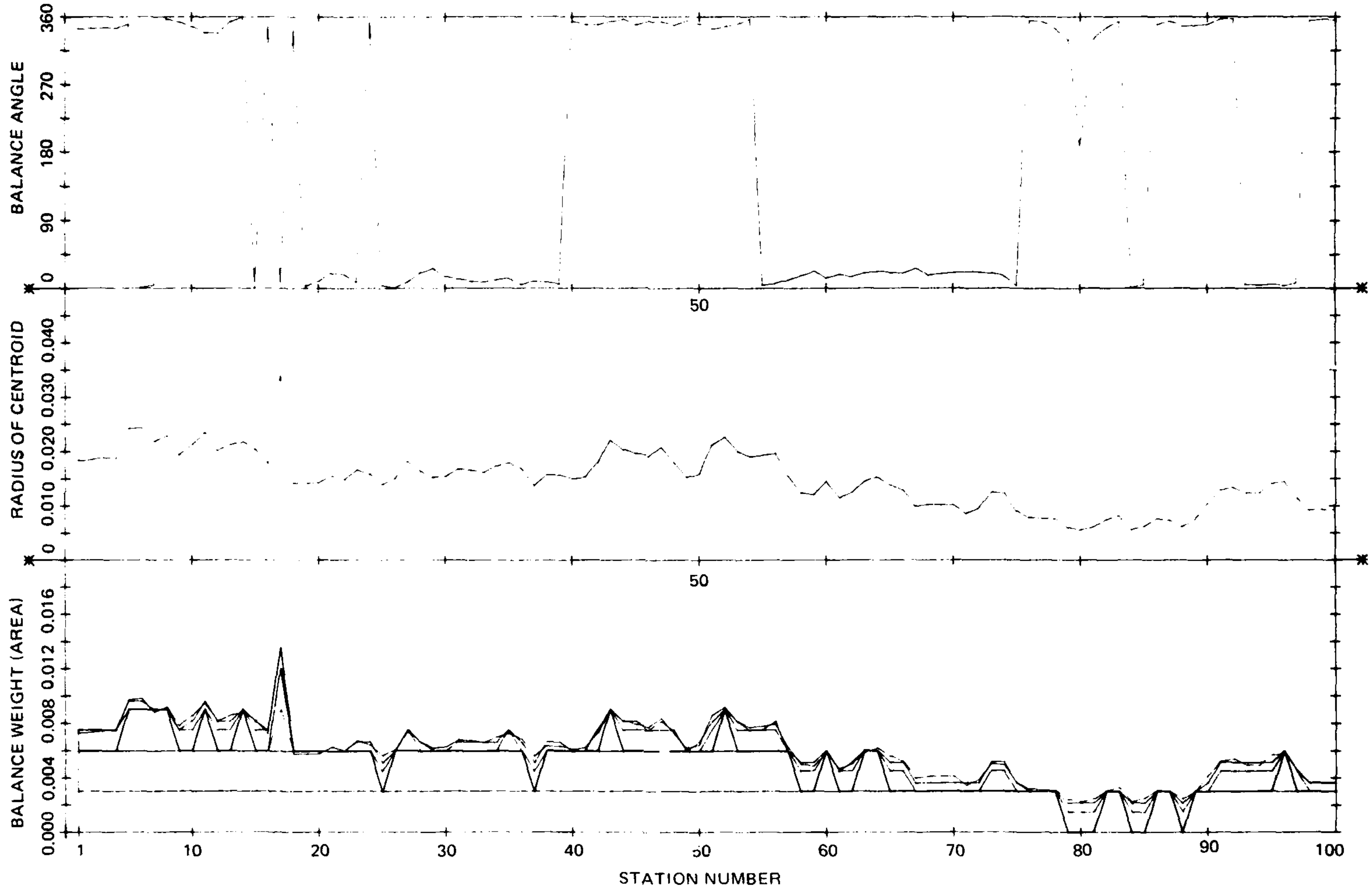

Figure 5. Computer plot of shaft mass distribution S/N 1U.

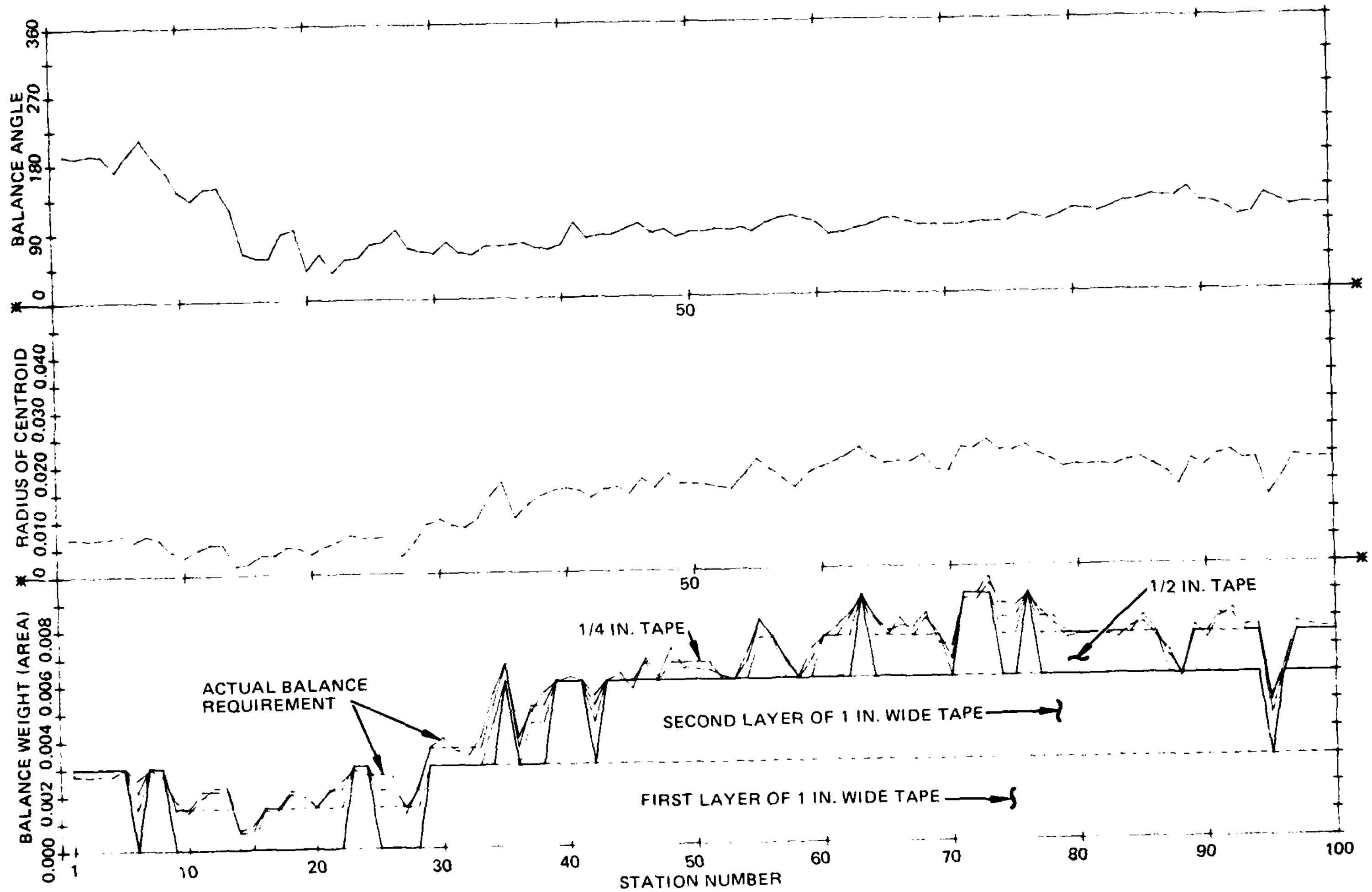

Figure 6. Computer plot of shaft mass distribution S/N 5U.

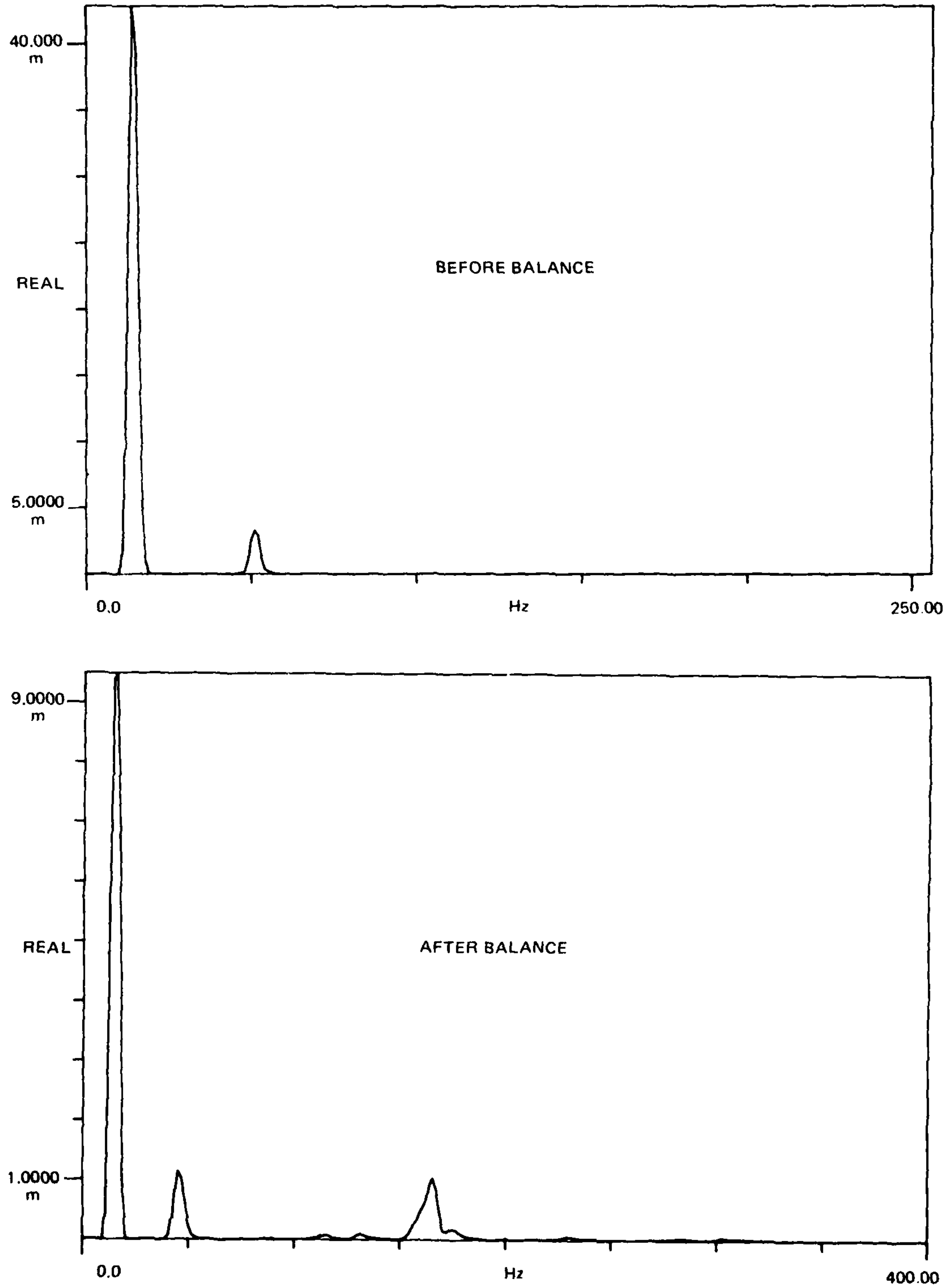

Figure 7. First critical speed (13 Hz).

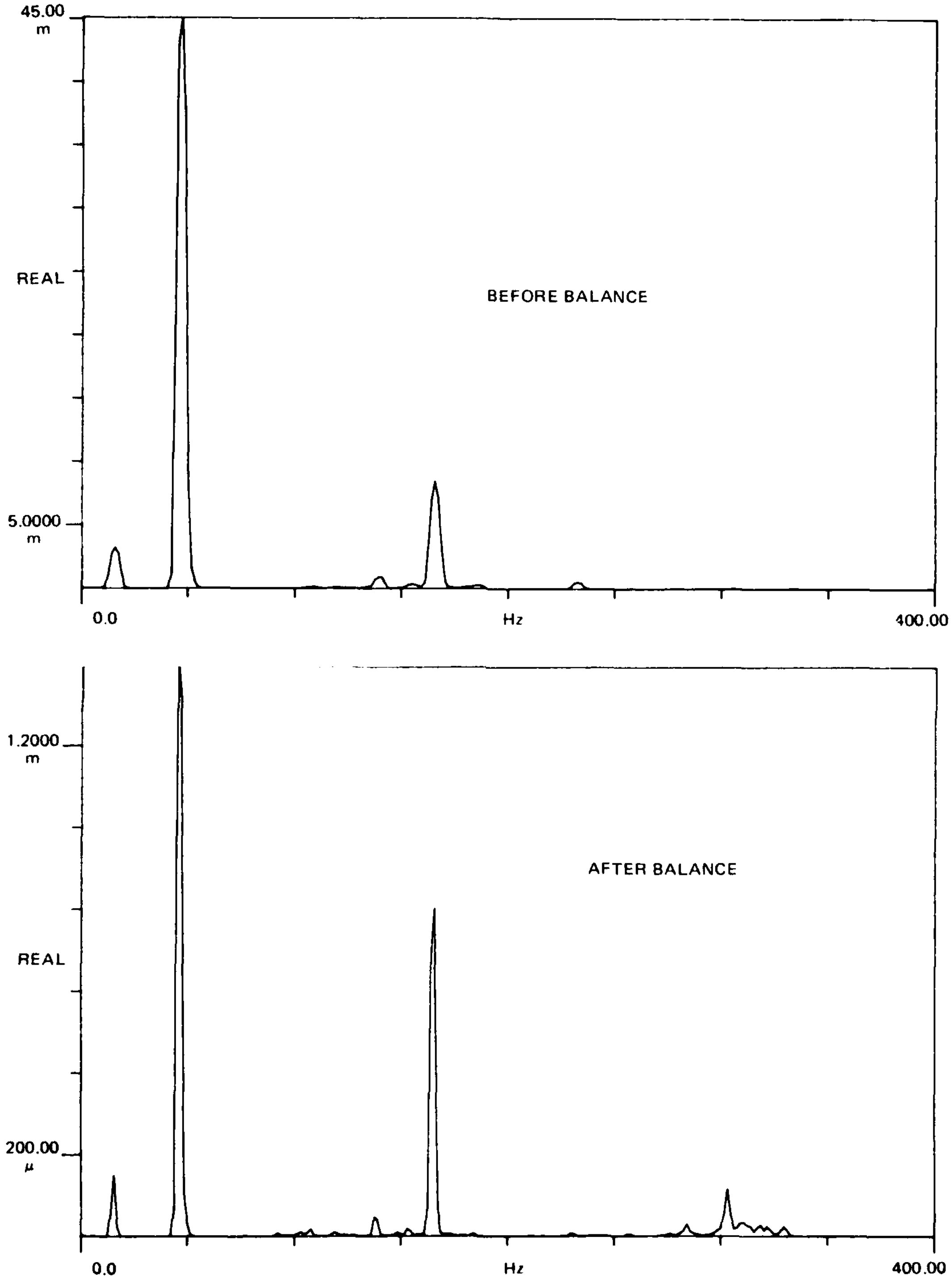

Figure 8. Second critical speed (50 Hz).

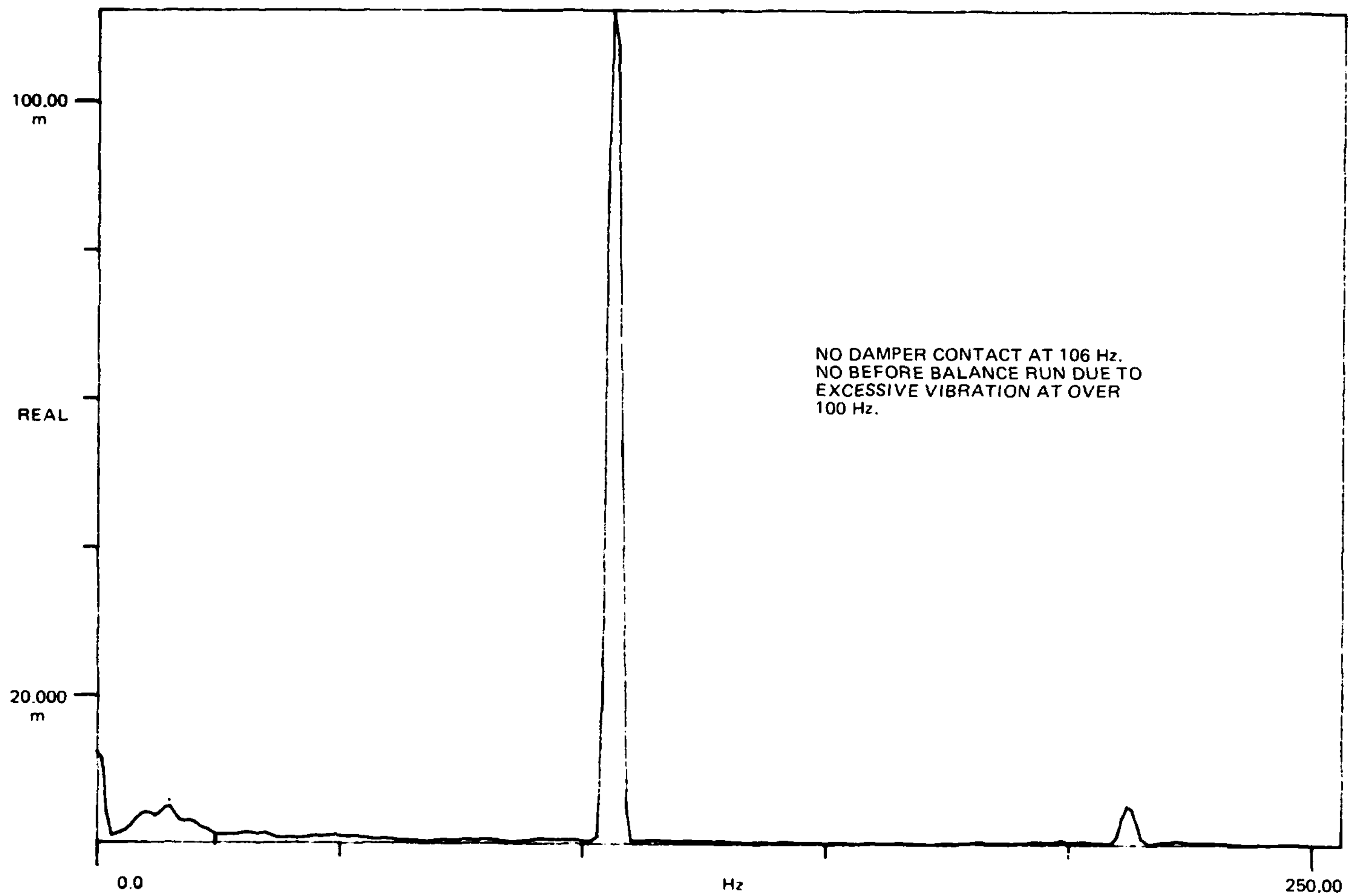

Figure 9. Third critical speed (106 Hz).

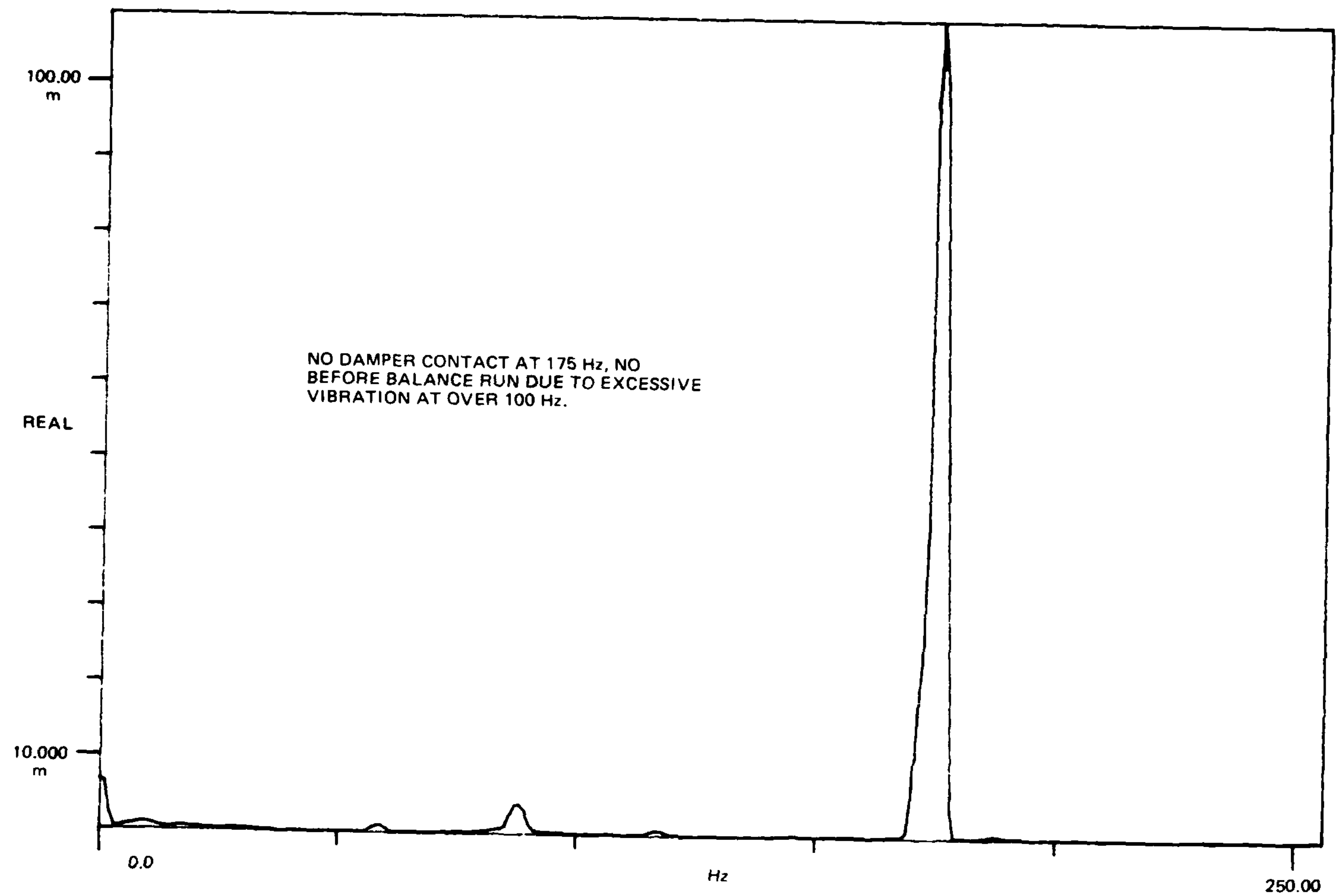

Figure 10. Fourth critical speed (175 Hz).

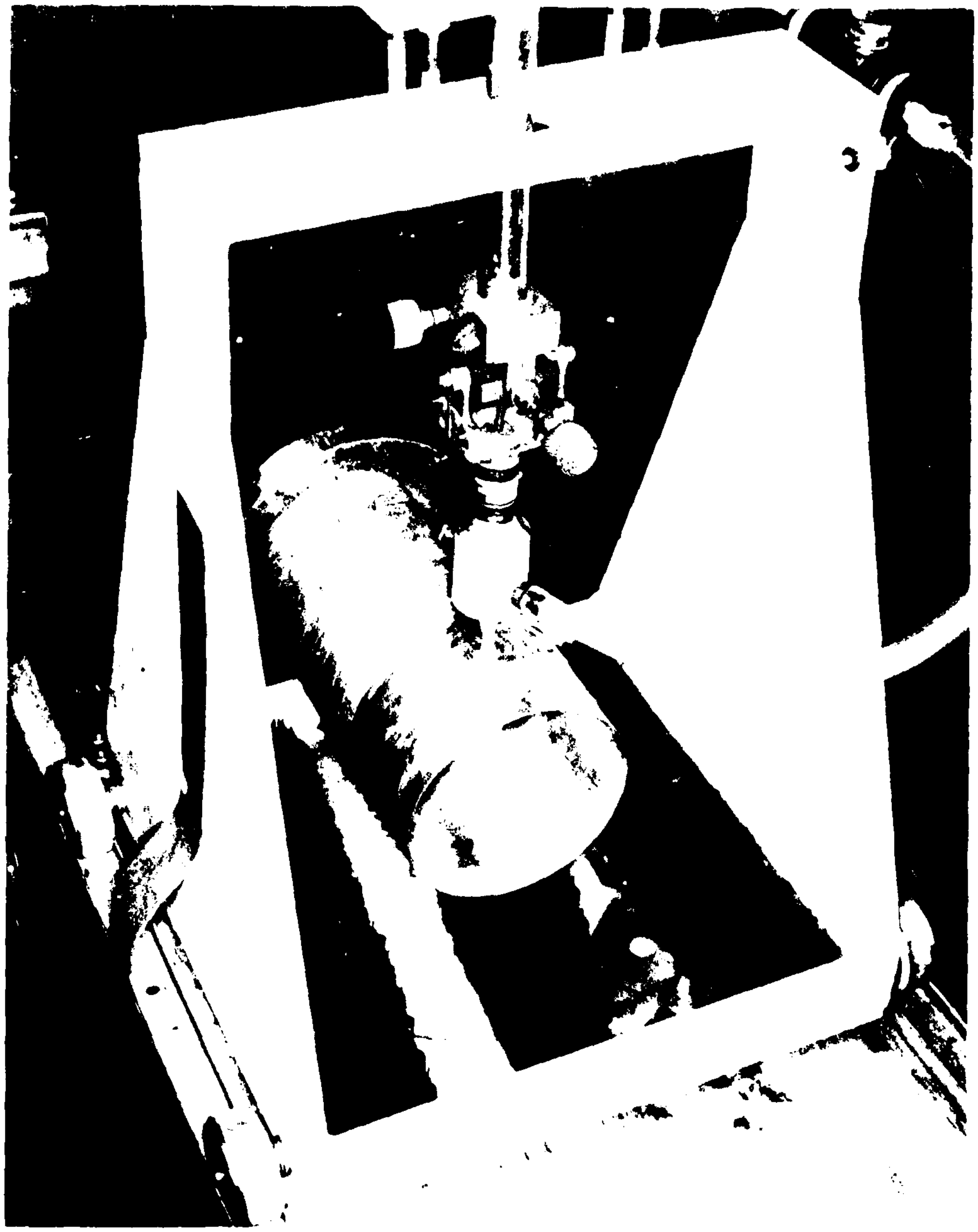

Figure 11. Calibration tube.

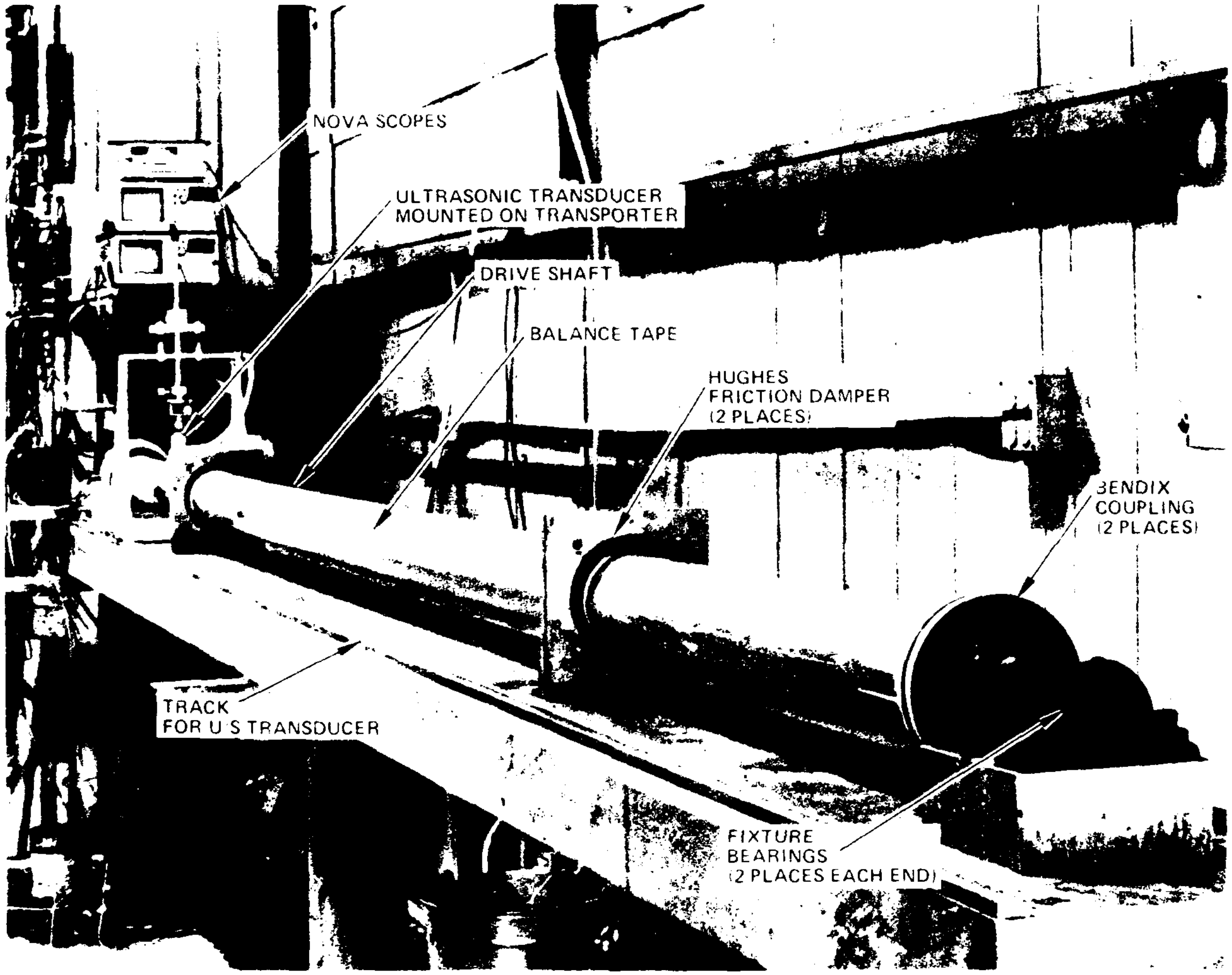

Figure 12. Balance machine setup.

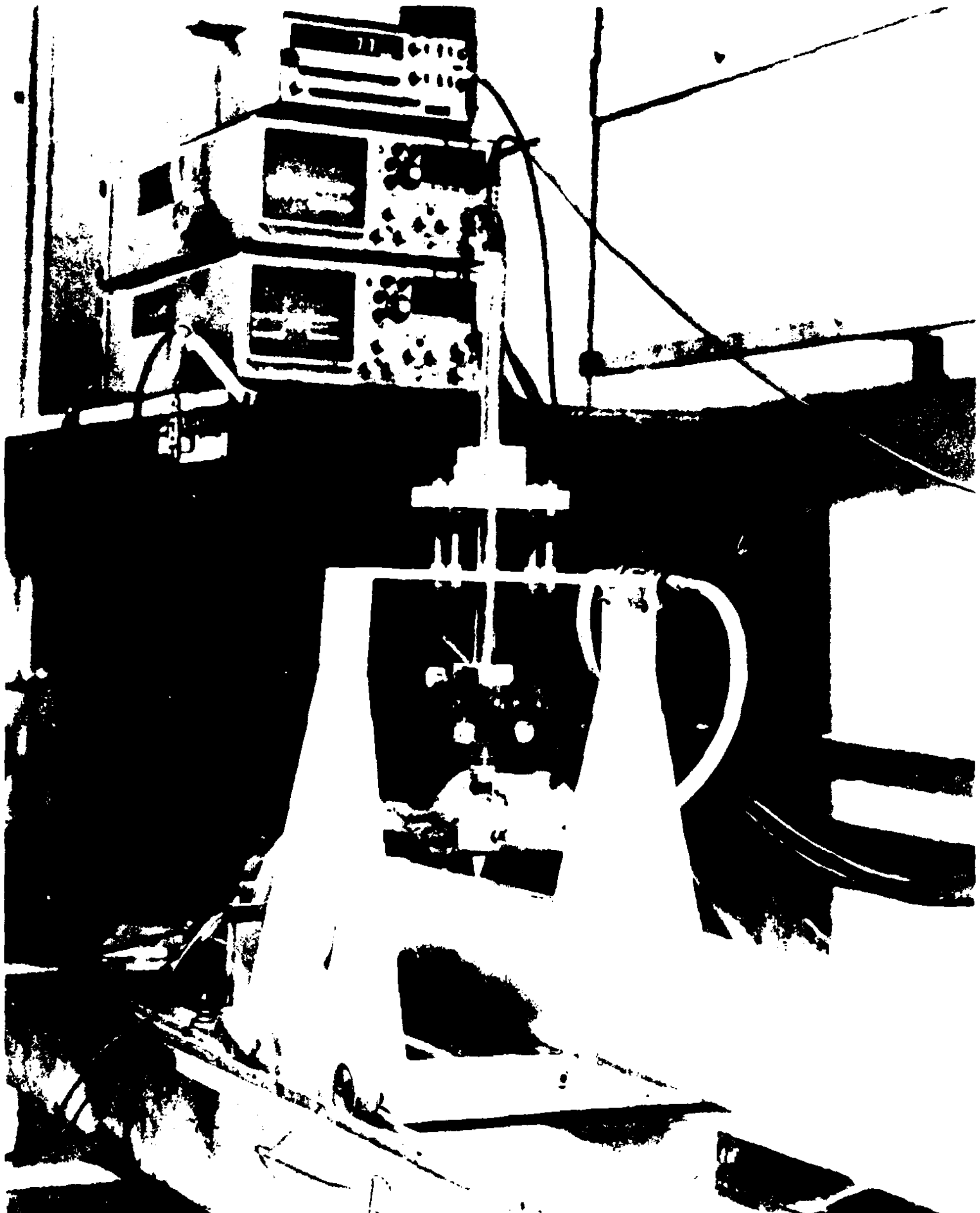

Figure 13. Nova scopes and transducer with transporter.

Figure 14. Balancing tape use and application.

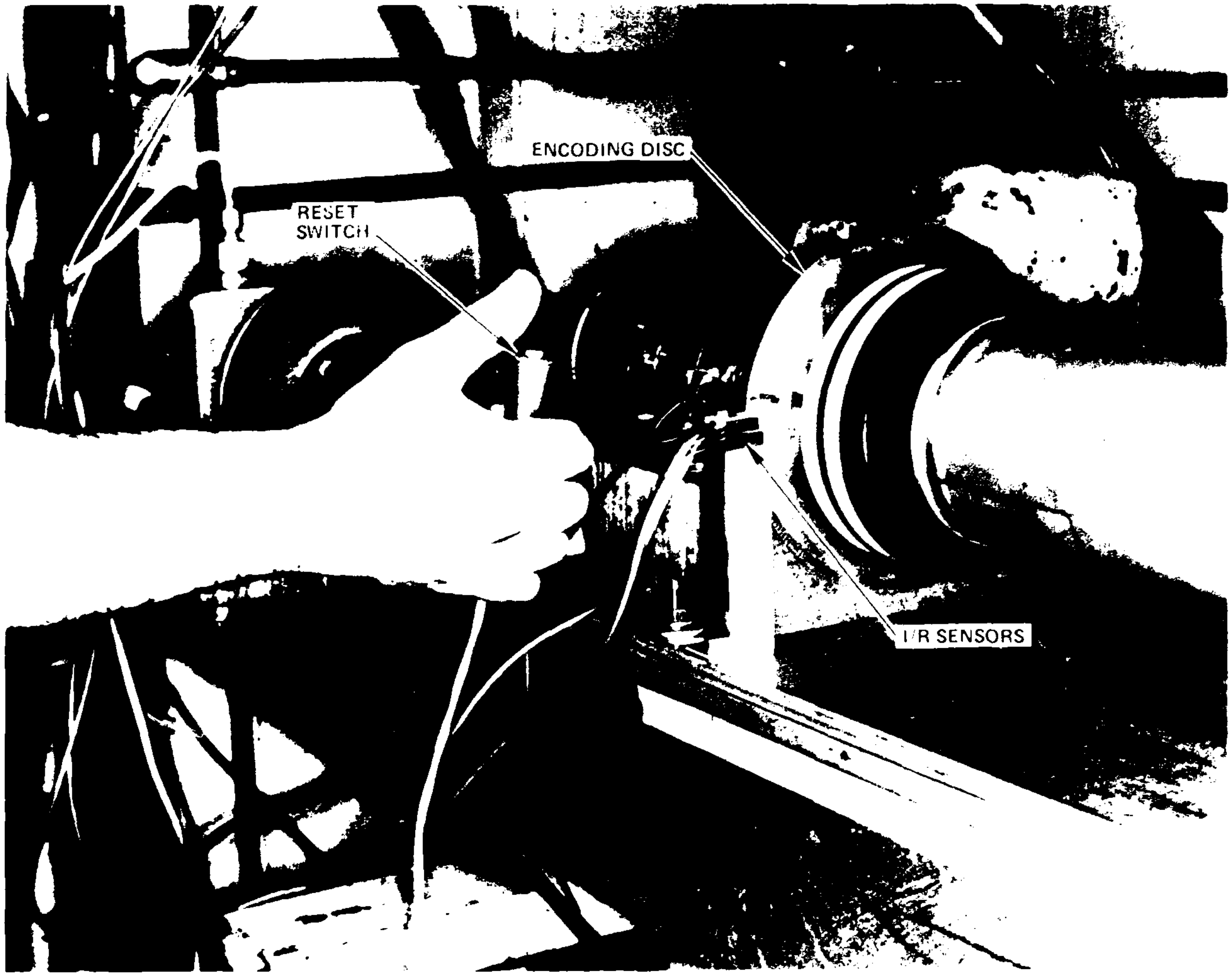

Figure 15. Encoding equipment with reset control for computer interface.

Figure 16. Computer terminal and print/plot equipment.

APPENDIX A
TAIL ROTOR DRIVE SHAFT POSITION ENCODER

Circuit Operation

The following description of the position encoder is referenced to the wiring schematic in Figure A-1.

Manual Mode

Upon power-up, a manual reset must be issued to set all registers to a ready state. The first 1/rev timing pulse (high) produces a corresponding high pulse at pin 8 of 74LS13(B); simultaneously, position 0 of the 250/rev produces a high at pin 6 of 74LS13(A). These simultaneous pulses cause register 74279(A) to become set, providing a "high" to pin 8 of 7408(C), and register 74279(B) to be reset which locks out all further set signals to register 74279(A) until a system reset is initiated. Each successive 250/rev pulse is then "added" with the set of register 74279(A) and fed to the transmission line where it is used to start and stop the HP computer pacer (H=run, L=stop). The next simultaneous 250/rev and 1/rev pulse will then clock the 7474(A) into a reset state which in turn resets register 74279(A), thus inhibiting all further pacer pulses until a system reset is initiated.

Automatic Mode

Automatic operation is basically the same as manual operation except a hand-shake operation between the encoding circuit and the computer is instituted and the "data in error automatic shutdown" circuit is enabled. In this case, the pacer S/S signal is disconnected from the transmission line and is first used to trigger the 74121 one shot, which in turn resets counter 7490 and register 7474(B). Secondly, the pacer S/S signal is "added" with the negation of register 7474(B) to form a new pacer S/S signal which is fed to the trans-mission line. When the pacer is started, pacer pulses are received via the transmission where they are counted by the 7490 counter.

After five pace pulses are received, the output of the counter will go high which sets register 7474(B), inhibiting the pacer S/S signal and stopping pacer. The pacer then remains off until the next 250/rev pulse and the sequence is repeated. Initial start-up and final shutdown are the same in the automatic mode as in the manual mode.

Notes:
1.) * 1/6 of a 7404 TTL hex inverter.
2.) All passive circuit components should be mounted vertically.
3.) Avoid parallel wire runs.
4.) Supply voltage is +5Vdc.
5.) (M) = Manual, (A) = Automatic mode.
6.) All IC pins not shown are not connected.
7.) Careful circuit layout is required for proper operation. Wire run length should be as short as possible & components must be placed as close as possible to their connection points.
8.) This circuit operates at frequency up to 1 MHz.

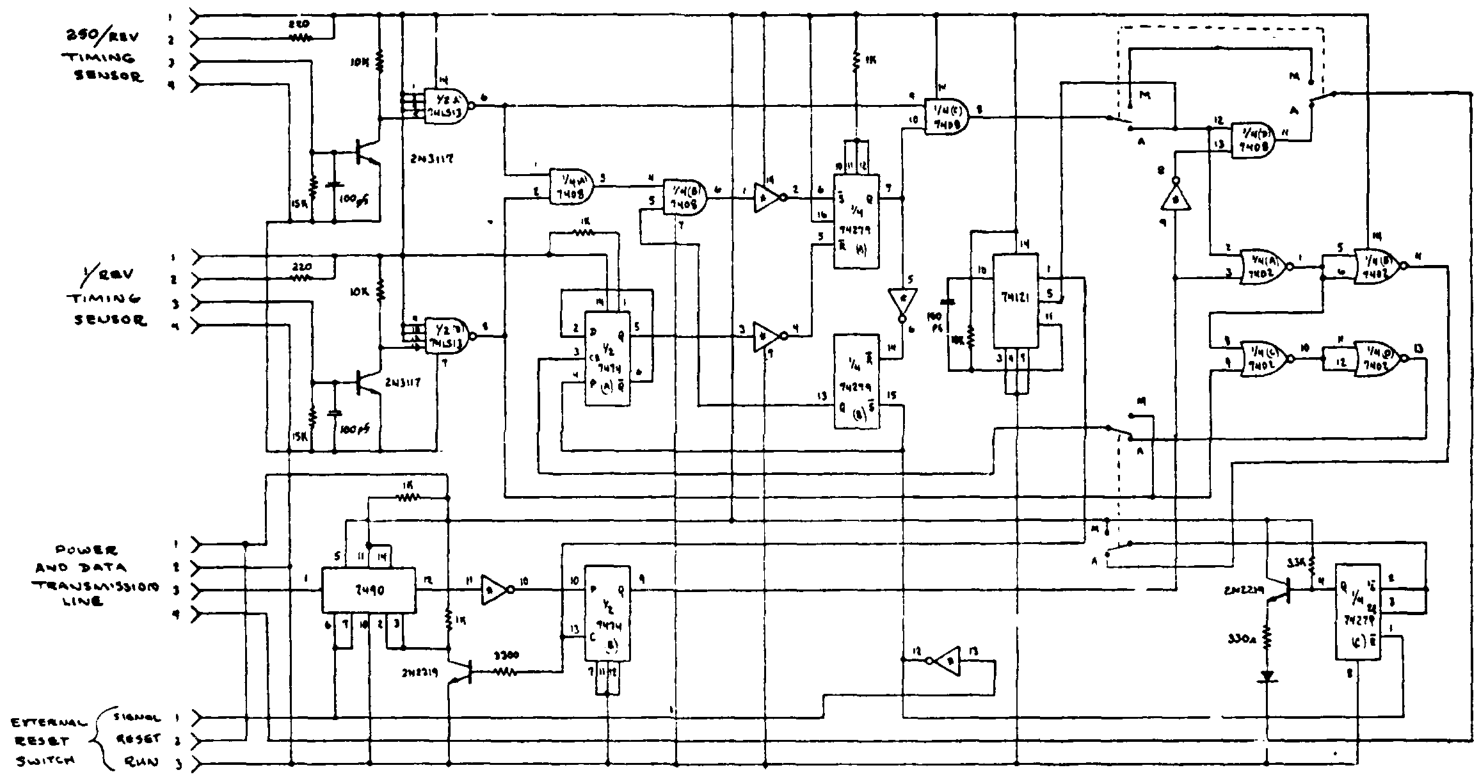

Figure A-1. Drive shaft position encoder.

In the automatic mode, the data error shutdown circuit is also enabled. Should the 250/rev timing pulse fall low before five pace pulses are received, the shaft travel will be considered too excessive for the data to be valid and the 7402 logic circuits will place the encoder circuit in a shutdown state, thus terminating operation until a system reset is initiated. Two internal dip switches are provided to switch between the auto/manual mode.

Data Rate

The data rate is limited by the response characteristics of the timing sensors and the external measurements to be taken. The rest of the circuit is capable of operating in excess of 1 MHz.

APPENDIX B

SUPER CRITICAL DRIVE SHAFT BALANCING SOFTWARE

SOFTWARE DOCUMENTATION AND LISTING

The Drive Shaft Software package consists of four interrelated programs. The first is the Calibration program called DCAL. This program allows recalculation of the calibration constants which are required for the proper running of the programs which follow it. To accomplish this the program requires two aluminum plates of known thickness and "Eccentricity" (actually what is needed is the difference in heights of the two plates relative to the fluid nozzle).

After recalculation of the calibration constants, the program called DSHAFT is run. This program reads the calibration values from the disk and lists them on the CRT terminal. It then calls the two programs which actually accomplish the task of determining the amount of aluminum tape required to balance the shaft. These two programs are called DS1 and DS2. The first, DS1, reads in data from the Nova Scopes and calculates the cross-sectional area required to balance each of the 100 stations along the length of the shaft. The program then returns control to DSHAFT, which calls DS2. DS2 then determines the number of layers of each width tape needed to balance each station. Once these values are determined the program both graphs and prints the calculated tape information. When this program completes it returns control to DSHAFT which executes an END statement and turns over control to basic.

DCAL

After calling the subroutine NORM to normalize the 2313 data acquisition system, the program prompts the operator to input the value of wall thickness for the first calibration plate and the relative eccentricity of that plate. One of the two plates may be taken to have zero eccentricity and used as a standard value. The second plate then has an eccentricity relative to the first.

The program then waits until the operator is sure that the proper calibration plate is in place under the fluid nozzle. When the operator types "G" then the program begins taking two sets of 100 voltage readings. One set contains the voltage output from the Nova Scope for Eccentricity while the other contains the values for Wall Thickness. The 100 readings of each set are then averaged to produce one voltage reading for Wall Thickness and one voltage reading for Eccentricity. The program then notifies the operator of any voltage errors

detected and of the completion of the first reading sequence. The operator is then asked to enter a new set of calibration values. These consist of the Wall Thickness and Eccentricity for the second plate. The program then waits until the operator types "G" before taking the next set of readings. This allows time to replace the first calibration plate by the second. Three sets of 100 readings are then taken and averaged to produce three voltage readings. These are the two Nova Scope readings plus a temperature reading. This third reading, the temperature, is used to account for variations in the readings due to the change in speed with temperature of the reflected signal.

Using the two sets of readings and calibration inputs, the program then calculates the slope and Zero voltage offset for both Wall Thickness and Eccentricity. These slopes have units of Volts per Inch (Volts/Inch) and are calculated using the equation for a line: $Y = m*X + b$, where "m" is the slope and "b" is the offset. These two parameters are computed using the following two equations which also include temperature offset:

Slope: m = (input plate2 - input plate1)/(volts plate2 - volts plate1)

offset: b = (input plate1) - (m*(volts plate1)) - (temp. volts)/100

These values are then printed on the external printer and the values saved on the disk in file DSDATA. The voltage and input data are also stored along with the calculated slopes and offsets.

Note: The sign of the slopes is unimportant, as the program DSHAFT sets the sign of the slope to correspond with the observed behavior of the output of the Nova Scopes.

DSHAFT

This program begins by reading the calibration values calculated by the program DCAL from the disk file DSDATA and displaying the values to the screen. However, prior to displaying the data the program corrects for the sign of the slope values by setting the Wall Thickness slope to a positive value and the Eccentricity slope to a negative value. The program then waits for the operator to hit Return before calling the FORTRAN subroutine DS1. When DS1 is called it is passed the calibration data from DSHAFT and returns the calculated values for Radius of centroid, Area required to balance the shaft, Angular location of the Centroid, Radius opposite Centroid, and First moment of inertia of the centroid. These calculated values are then stored on disk file DSDATA by DSHAFT. Next, they are passed to the FORTRAN subroutine, DS2, which completes the calculations. When DS2 completes and returns control to DSHAFT the program cycle is complete and DSHAFT ends.

DS1

This is the key program in the sequence. It is responsible for computing the location and magnitude of the imbalance at each station. To do this the program requires two calibration slopes: the wall thickness offset value at zero volts and the Radius of the shaft at zero degrees azimuth. Using these values the program takes 250 readings at each station at even angular divisions around the shaft. The readings are triggered by a change in voltage on a control channel which acts as a pacer for the readings. When the voltage on the control channel goes from a value below 2 volts to a value in excess of 6 volts the program takes one reading on each of three channels. The first channel is the Eccentricity voltage, the second is the Wall Thickness voltage and the third is the Temperature voltage. The program then waits for the next low to high transition before taking an additional reading. This continues for 250 readings around the shaft. (The program acts as a positive edge trigger device for data acquisition.) If after 250 readings it is determined that additional triggers are occurring on the pacer channel then an error condition occurs and the program prepares to retake the last set of readings after the operator hits the return key.

After the 250 sets of three readings have been taken the program calculates the location of the centroid and the centroid magnitude as follows:

a. First, the voltage reading for Eccentricity is converted into a Radius value and the voltage for Wall Thickness is converted into inches. Both these values have a correction for temperature variations by adding the temperature voltage divided by 100 to the inches value. (Note this is an empirical correction.) The centroid is then calculated by summing the individual moments about the circle. The individual moments are determined to be the area of that slice times the radius to the center of that area. The area is determined as

   Area = (Wall thickness)*(Radius)*(Delta Theta)

   This is a rectangular approximation to the area. The radius used is the radius determined by the eccentricity minus half the wall thickness.

b. The centroid is determined in Cartesian coordinates using the sine and cosine to determine the Y and X components of the moment vectors. These values are summed around the circle to determine the Centroid of the entire circular slice of the shaft. These values are then converted into Polar coordinates using R=SQRT((X*X)+(Y*Y)) and Theta=Arctan(Y/X).

c. These values are then used to determine the amount of area required to balance the shaft at that station. The tape must be added at 180 degrees from the centroid of the shaft. This angle is determined and the actual radius of that location is calculated. This value is later used to determine the moment of a piece of tape at that location. The Radius of the centroid times the total cross-sectional area determines the magnitude of the imbalance. An equivalent moment must be added in the opposite direction in order to balance the shaft. The area of tape times its moment arm is this balance. Therefore, the area of tape needed = (Radius of the Centroid)*(Total cross-sectional area)/Radius opposite the Centroid).

DS2

This FORTRAN program is passed the information calculated by DS1 and computes the number of tape layers needed to balance each station. It then graphs and prints this data along with a graph of the radius of the centroid and the angle opposite the centroid.

The determination of the number of layers of each tape is based on an iterative process for the first size tape and then additional layers of smaller tape as needed. No more than one layer of the smaller layers is needed at any station due to a binary approximation method because each smaller layer of tape is 1/2 the size of the preceding layer. Therefore, only the tape widths 1 inch, 1/2 inch and 1/4 inch are needed.

To determine the effect of each layer of tape, the radius of the shaft at the balance angle is used and updated as additional layers of tape are added.

PROGRAM DCAL

```
DCAL    T=00004 IS ON CR19513 USING 00012 BLKS R=0016

10REM THIS IS THE DRIVE SHAFT BALANCING CALIBRATION PROGRAM "DCAL"
20FILES0,DSDATA
30DIM Z[2],W[102],E[102],T[100]
40PRINT
50CALLDATER(1)
60PRINT
70CALLNORM(1)
80PRINT
90PRINT "WHAT IS THE WALL THICKNESS";
100INPUT W[1]
110PRINT
120PRINT "WHAT IS THE ECCENTRICITY";
130INPUT E[1]
140PRINT
150REM THIS GOSUB WAITS UNTIL YOU ARE READY TO TAKE DATA
160GOSUB 800
170LET Z[1]=0
180LET Z[2]=0
190LET E3=0
200CALLAISOV(100,-343,E[3],E1)
210CALLAISOV(100,-344,W[3],E2)
220REM THIS GOSUB CHECKS THE ERROR RETURN VARIABLES En
230GOSUB 850
240IF E1+E2=0THEN 270
250PRINT "CHECK INPUTS AND RETAKE FIRST SET"
260GOTO 160
270PRINT
280PRINT " FIRST READING SET DONE"
290FOR I=1TO 100
300LET Z[1]=Z[1]+E[2+I]
310LET Z[2]=Z[2]+W[2+I]
320NEXT I
330LET Z[1]=Z[1]/100
340LET Z[2]=Z[2]/100
350PRINT "NEXT SET OF READINGS"
360PRINT "WHAT IS THE WALL THICKNESS";
370INPUT W[2]
380PRINT "WHAT IS THE ECCENTRICITY";
390INPUT E[2]
400REM THIS GOSUB WAITS UNTIL YOU ARE READY TO TAKE DATA
410GOSUB 800
420CALLAISOV(100,-343,E[3],E1)
430CALLAISOV(100,-344,W[3],E2)
440CALLAISOV(100,-345,T[1],E3)
450REM THIS GOSUB CHECKS THE ERROR RETURN VARIABLES
460GOSUB 850
470IF E1+E2+E3=0THEN 500
480PRINT " CHECK INPUTS AND RETAKE SECOND SET"
490GOTO 410
500PRINT "DONE, SECOND SET COMPLETE."
510FOR I=2TO 100
520LET E[3]=E[3]+E[I+2]
530LET W[3]=W[3]+W[I+2]
540LET T[1]=T[1]+T[I]
550NEXT I
560LET E[3]=E[3]/100
570LET W[3]=W[3]/100
580LET T[1]=T[1]/10000
590REM T IS THE TEMP CONSTANT IN INCHES CHANGE
600LET W=(W[2]-W[1])/(W[3]-Z[2])
```

PROGRAM DCAL (CONT)

```
610LET E=(E[2]-E[1])/(E[3]-Z[1])
620LET E0=E[1]-Z[1]*E-T[1]
630LET W0=W[1]-Z[2]*W-T[1]
640PRINT #6
650PRINT #6;" THE FOLLOWING CONSTANTS WERE TAKEN ON:"
660CALLDATER(6)
670PRINT #6
680PRINT #6;"WALL THICKNESS CONSTANT (Inches/Volt) = ";W
690PRINT #6;"WALL THICKNESS OFFSET   (Inches) = ";W0
700PRINT #6;"ECCENTRICITY CONSTANT   (Inches/Volt) = ";E
710PRINT #6;"ECCENTRICITY OFFSET     (Inches) = "E0
720PRINT #6;"TEMPERATURE OFFSET      (Temp/1000) = ";T[1]
730PRINT "OK (Y or N)";
740INPUT A$
750IF A$="N"THEN 90
760PRINT #2,1
770PRINT #2;E0,W0,E,W,W[1],W[2],E[1],E[2],T[1],Z[1],Z[2],E[3],W[3]
780CHAIN "DSHAFT"
790REM WAIT GOSUB
800PRINT "When you are ready to take data type G and Retrun."
810INPUT A$
820IF A$#"G"THEN 810
830RETURN
840REM VOLTAGE ERROR SUBROUTINE
850IF E1#0PRINT "Voltage error on Eccentricity reading Channel 343"
860IF E2#0PRINT "Voltage error on Wall thickness reading Ch. #344"
870IF E3#0PRINT "Voltage error on Temperature reading  Channel 345"
880PRINT "VOLTAGE ERROR CHECKSUM = ";E1+E2+E3
890PRINT
900RETURN
910END
```

PROGRAM DSHAFT

```
DSHAFT T=00004 IS ON CR19513 USING 00012 BLKS R=0016

10REM THIS IS THE DRIVE SHAFT BALANCING PROGRAM "DSHAFT"
20FILES0,DSDATA
30REM W[*]=BWGHT[*],A[*]=ATHETA[*],R[*]=RBAR,E=ECC, B=BAL
40DIM E[100],B[100],W[100],R[100],A[100]
50READ #2,1
60FOR I=1TO 13
70READ #2;E[I]
80NEXT I
90REM
100REM THE FOLLOWING TWO ASSIGNMENTS ARE TO ACCOUNT FOR THE
110REM  FACT THAT THE SLOPE OF THE ECCENTRICITY VOLTS SHOULD BE
120REM  NEGATIVE WHILE THE SLOPE OF THE WALL THICKNESS VOLTAGE
130REM  SHOULD HAVE A POSITIVE SLOPE
140LET E[3]=-ABS(E[3])
150LET E[4]=ABS(E[4])
160PRINT "OFSET VALUE FOR ECCENTRICITY= ";E[1]
170PRINT "ECCENTRICITY SLOPE(In V)= ";E[3]
180PRINT "OFSET VALUE FOR WALL THICKNESS= ";E[2]
190PRINT "WALL THICKNESS SLOPE (In V)= ";E[4]
200PRINT " CALIBRATION VALUES USED"
210PRINT
220PRINT "WALL THICKNESSES USED :  FIRST = ";E[5];" SECOND = ";E[6]
230PRINT "ECCENTRICITIES USED :    FIRST = ";E[7];" SECOND = ";E[8]
240PRINT "VOLTAGES READ :  FIRST SET        SECOND SET"
250PRINT
260PRINT "CHANNEL 343";TAB(18);E[10];TAB(35);E[12]
270PRINT "CHANNEL 344";TAB(18);E[11];TAB(35);E[13]
280PRINT
290PRINT "TEMPERATURE OFFSET";E[9]
300PRINT
310PRINT
320PRINT "WHEN READY HIT RETURN"
330INPUT A$
340CALLDATER(1)
350CALLDS1(E[1],B[1],W[1],R[1],A[1])
360CALLDATER(6)
370READ #2,2
380FOR I=1TO 100
390IF I=51READ #2,3
400PRINT #2;E[I]
410NEXT I
420READ #2,4
430FOR I=1TO 100
440IF I=51READ #2,5
450PRINT #2;B[I]
460NEXT I
470READ #2,6
480FOR I=1TO 100
490IF I=51READ #2,7
500PRINT #2;W[I]
510NEXT I
520READ #2,8
530FOR I=1TO 100
540IF I=51READ #2,9
550PRINT #2;R[I]
560NEXT I
570READ #2,10
580FOR I=1TO 100
590IF I=51READ #2,11
600PRINT #2;A[I]
610NEXT I
620PAUSE
630CALLDS2(E[1],B[1],W[1],R[1],A[1])
640END
```

PROGRAM DS1

```
DS1     T=00004 IS ON CR19513 USING 00038 BLKS R=0294

FTN4,L
      SUBROUTINE DS1(ECC,BAL,BWGHT,RBAR,ATHETA)
      DIMENSION VOLTS(3,250),V(75),ECC(100),BAL(100),ITI(5),MTIM(5)
      DIMENSION BWGHT(100),RBAR(100),ATHETA(100)
       DATA PI/3.141592654/
       DATA TWOPI/6.2831853/
       DATA DTHETA/.0251327/
       DATA ISTAT/1/
C    THIS PROGRAM CALCULATES THE CENTROID OF A PLANAR SLICE OF A DRIVE
C     SHAFT TAKEN NORMAL TO THE AXIS OF ROTATION.
C
C    THE DATA IS TAKEN IN POLAR COORDINATES AND THEN CONVERTED INTO
C     CARTESIAN FORM USING THE RELATIONS:
C                                             X=rCOS(theta)
C                                             Y=rSIN(theta)
C      VOLTS(1,I) WILL HOLD THE VALUES FOR ECCENTRICITY
C      VOLTS(2,I) WILL HOLD THE VALUES FOR WALL THICKNESS
C      VOLTS(3,I) WILL HOLD THE VALUES FOR WATER TEMPERATURE
C      RADIUS WILL HOLD THE LOCATION OF THE Mc FOR THE SECTOR
C      AREA WILL HOLD THE CALCULATED AREA OF EACH SECTOR
C
C      THE FOLLOWING ASSUMPTIONS ARE MADE:
C         1.  THE SECTOR IS APPROX. A RECTANGLE
C         2.  THE CENTER OF MASS, Mc, FOR THE SECTOR IS HALF
C             THE WALL THICKNESS FROM THE OUTER EDGE.
C         3.  THE SECTOR HAS UNIFORM DENSITY
C
C       XA IS THE SUMATION VARIABLE FOR X MULTIPLIED BY AREA
C       YA IS THE SUMATION VARIABLE FOR Y MULTIPLIED BY AREA
C       A  IS THE SUMATION VARIABLE FOR THE AREA
C
C      THIS BEGINS THE DUMMY ARRAY VALUE SECTION FOR DEBUG
C      THIS BEGINS THE INITIALIZATION SECTION FOR DEFINING CONSTANTS
       WRITE(1,2)
       READ (1,*) IPRINT
       WRITE(1,3)
       READ (1,*) RCON
             RCON=RCON/2
       WRITE(1,13)
       READ (1,*) PF
                 V1=ECC(1)
                 CON1=ECC(3)
                 V2=ECC(2)
                 CON2=ECC(4)
         WRITE(1,17)CON1,CON2,RCON
       PMAX=6.0
       PMIN=2.0
C      THIS IS THE DATA ACQUISITION LOOP
       CALL NORM(1)
C      CALL EXEC(11,ITI,IYEAR)
1       DO 50 I=1,250
25      CALL AISOF(1,346,PVOLT,IVERR)
        IF (PVOLT.GT.PMIN) GOTO 25
26      CALL AISOF(1,346,PVOLT,IVERR)
        IF (PVOLT.LT.PMAX) GOTO 26
        CALL AISOF(+3,343,VOLTS(1,I),IVERR)
50      CONTINUE
        CALL PACER(1,  ,0,1,IERR)
        CALL AISOF(-75,-346,V,IERR)
```

PROGRAM DS1 (CONT)

```
            CALL PACER(0,0,0,1,IERR)
            VMIN=V(1)
            VMAX=V(1)
            DO 27 I=2,75
            IF (V(I).LT.VMIN) VMIN=V(I)
            IF (V(I).GT.VMAX) VMAX=V(I)
      27    CONTINUE
              IF ((VMAX-VMIN) .LT. 2) GOTO 28
            WRITE(1,24) ISTAT
            READ (1,*) HALT
            GOTO 1
C           CALL EXEC(11,MTIM,IYEAR)
C           XMIN=(MTIM(3)-ITI(3))*60.0
C           SEC=XMIN+MTIM(2)-ITI(2) + ((MTIM(1)-ITI(1))/100.0)
C           WRITE (6,20) SEC
C     SET SUMATION VARIABLES TO ZERO
      28     XA=0
             YA=0
              A=0
C
C          THIS BEGINS THE CALCULATION SECTION
C
            V1=VOLTS(1,1)-CON1
           DO 100 I=1,250
           IF (PF.EQ.1) WRITE(6,18) I,VOLTS(1,I),VOLTS(2,I),VOLTS(3,I)
           VOLTS(1,I)=RCON+VOLTS(1,I)+CON1-V1 + VOLTS(3,I)*.01
           VOLTS(2,I)=VOLTS(2,I)+CON2+V2 + VOLTS(3,I)*.01
           RADIUS=VOLTS(1,I)-(VOLTS(2,I)/2)
           AREA=VOLTS(2,I)*RADIUS*DTHETA
           IF (PF.EQ.1) WRITE(6,19) VOLTS(1,I),VOLTS(2,I),RADIUS,AREA
            THETA=(I-1)*DTHETA
            XA= XA+(AREA*RADIUS*COS(THETA))
            YA= YA+(AREA*RADIUS*SIN(THETA))
            A= A+AREA
      100  CONTINUE
           XBAR= XA/A
           YBAR= YA/A
           RBAR(ISTAT)=SQRT((XBAR*XBAR)+(YBAR*YBAR))
           THETA=ATAN2(YBAR,XBAR)
C
C          BEGIN PRINTOUT SECTION
           THETA=THETA*360/TWOPI
           IF (THETA .LT. 0) THETA=360+THETA
           WRITE(IPRINT,7) ISTAT
           WRITE(IPRINT,9)
           WRITE(IPRINT,10) RBAR(ISTAT)
           WRITE(IPRINT,11) THETA
           WRITE(IPRINT,12) A
           IF (THETA .LT. 180) ANGLE=THETA+180.
           IF (THETA .GE. 180) ANGLE=THETA-180.
           THETA=ANGLE
           ANGLE=(ANGLE+25)/36
           ITHETA=INT(ANGLE)
           DT=ANGLE-FLOAT(ITHETA)
           ITHETA=ITHETA+1
           IANGLE=ITHETA+1
           IF (IANGLE .GT. 250) IANGLE=1
           DELTA=VOLTS(1,IANGLE)-VOLTS(1,ITHETA)
           ECC(ISTAT)=VOLTS(1,ITHETA)+(DELTA*DT)
           WRITE(IPRINT,14) THETA,ECC(ISTAT)
            ATHETA(ISTAT)=THETA
            BAL(ISTAT)=A*RBAR(ISTAT)
            BWGHT(ISTAT)=BAL(ISTAT)/ECC(ISTAT)
```

```
            WRITE(IPRINT,21) BWGHT(ISTAT)
           IF (ABS(RBAR(ISTAT)) .LT. 0.0001) WRITE(IPRINT,15)
             ISTAT=ISTAT+1
             WRITE(IPRINT,16)
             IF (ISTAT .LE. 100) GOTO 1
      2    FORMAT("WHAT IS THE PRINTER (1 OR 6)?")
      3    FORMAT(/"DIAMETER IN INCHES?",)
      4    FORMAT("Eccentricity Constant (Inches Volt)?",)
      5    FORMAT(,"Wall Thickness Const. (Inches Volt)?",)
      6    FORMAT(,"Water Temperature     (Degrees/Volt)?",)
      7    FORMAT("STATION NUMBER ",I3)
      9    FORMAT("CENTROID IN POLAR COORDINATES:")
     10     FORMAT("  RADIUS IN INCHES = ",F8.4)
     11     FORMAT("  DEGREES AZIMUTH  = ",F5.2)
     12     FORMAT(8X,"TOTAL X-SECTIONAL AREA = ",F10.4)
     13     FORMAT("DO YOU WANT A DATA DUMP (1=YES)?")
     14     FORMAT("ADD WEIGHT AT ",F5.2," DEG AZIMUTH,   RADIUS =",F8.4)
     15    FORMAT("** BALANCED **")
     16    FORMAT("_______________________________________________")
     17    FORMAT("ECC CONST=",F8.4,"WALL CONST=",F8.4/"RADIUS=",F8.4)
     18    FORMAT(I3,"ECC V.=",F8.5," WALL V.=",F8.5," TEMP V.=",F8.5)
     19    FORMAT("ECC=",F8.5," WALL=",F8.5," RADIUS=",F8.5,"AREA=",F8.5)
     21    FORMAT("(AREA)*(CENTROID RADIUS)/(ECCENTRICITY",
          $" OPPOSITE CENTROID)=",F7.5)
     22     FORMAT("WHAT IS THE OFFSET VALUE FOR ECCENTRICITY?",)
     23     FORMAT("WHAT IS THE OFFSET VALUE FOR WALL THICKNESS?",)
     24    FORMAT(//"ERROR--, MORE THAN 250 PULSES/BELIEVE."/
          $"RESET FOR STATION ",I3," THEN HIT RETURN.")
           RETURN
           END
      $
```

PROGRAM DS2

```
DS2     T=00004 IS ON CR19513 USING 00025 BLKS R=0000

FTN4,L
      SUBROUTINE DS2(ECC,BAL,BNGHT,RBAR,ATHETA)
      DIMENSION T(3),IX(8),IY(11),ECC(100),BAL(100)
      DIMENSION BNGHT(100),RBAR(100),ATHETA(100),YDATA(100,3)
      DIMENSION YHT(100)
      INTEGER TCT(100,3),BTIC,RTIC
       DATA BMAX/0.0/
       DATA RMAX/0.0/
       DATA ISTAT/1/
       DATA IX/14,2HST,2HAT,2HIO,2HN ,2HNU,2HMB,2HER
       DATA IY/20,2HBA,2HLA,2HNC,2HE ,2HWE,2HIG,2HHT,2H(A,2HRE,2HA)
       DATA T/.3,.15,.0625/
      DO 2 I=1,100
       TCT(I,1)=0
       TCT(I,2)=0
       TCT(I,3)=0
        YHT(I)=0
       IF (RBAR(I).GT.RMAX) RMAX=RBAR(I)
       IF (BNGHT(I).GT.BMAX) BMAX=BNGHT(I)
2     CONTINUE
13     FORMAT(X)
17    FORMAT(10X,"Station    1 inch   1/2 inch   1/4 inch Tape",3X
     $ " Angle (Degrees)")
18    FORMAT(12X,I3,7X,I2,7X,I2,8X,I2,14X,I6)
      BTIC=10
      BSCALE=300
      IF (BMAX .LE. .01) GOTO 300
      BSCALE=150
      IF (BMAX .LE. .02) GOTO 300
      BSCALE=60
      IF (BMAX .LE. .05) GOTO 300
      BTIC=15
      BSCALE=40
      IF (BMAX .LE. .075) GOTO 300
      BTIC=10
      BSCALE=30
      IF (BMAX .LE. .1) GOTO 300
      BTIC=15
      BSCALE=20
      IF (BMAX .LE. .15) GOTO 300
      BTIC=10
      BSCALE=15
300    RTIC=10
       RSCALE=150
       IF (RMAX .LE. .02) GOTO 500
       RSCALE=60
       IF (RMAX .LE. .05) GOTO 500
       RTIC=15
       RSCALE=40
       IF (RMAX .LE. .075) GOTO 500
       RTIC=10
       RSCALE=30
       IF (RMAX .LE. .1) GOTO 500
       RTIC=15
       RSCALE=20
       IF (RMAX .LE. .15) GOTO 500
       RTIC=10
       RSCALE=15
       IF (RMAX .LE. .2) GOTO 500
       RSCALE=6
```

```
500    CALL PLTID(7)
       CALL LLEFT
       CALL SFACT(15.,10.)
       CALL PLOT(0.,0.,-3)
       CALL PLOT(.5,.5,3)
       CALL SYMB(.5,.5,.12,3,0.,-2)
       DO 515 I=1,BTIC
       YI=.5+(I*.BTIC)
       CALL SYMB(.5,YI,.1,13,90.,-2)
515    CONTINUE
       CALL SYMB(.1,3.5,.1,11,0.,-2)
       DO 520 I=1,9
       XI=.5+(1.4*I)
       CALL SYMB(XI,3.5,.1,13,0.,-2)
520    CONTINUE
       CALL SYMB(14.[illegible],.5,.1,11,0.,-2)
       CALL SYMB(14.[illegible],.5,.1,11,0.,-2)
       DO 530 I=1,BTIC
       YI=3.5-(I*3.BTIC)
       CALL SYMB(14.5,YI,0.1,13,90.,-2)
530    CONTINUE
       DO 535 I=1,10
       XI=14.5-(1.4*I)
       CALL SYMB(XI,.5,.1,13,0.,-2)
535    CONTINUE
       XTIC=1
       XI=.64
       CALL SYMB(0.64,.5,.1,13,0.,-1)
       DO 536 I=1,11
       CALL NUMB(XI,.25,.1,XTIC,0.,-1)
       XTIC=I*10
       XI=(I*1.4)+.375
536    CONTINUE
       CALL SYMB(6.7,.05,.12,ID(1),0.,1)
       CALL SYMB(.2,0.8,.12,IY(1),90.,1)
       DO 538 I=0,4
       YI=.225+(I*0.6)
       YTIC=I*0.6/BSCALE
       CALL NUMB(.4,YI,.1,YTIC,90.,+3)
538    CONTINUE
       CALL PLOT(.5,3.5,3)
       DO 540 I=0,RTIC
       YI=3.5+(I*3./RTIC)
       CALL SYMB(.5,YI,.1,13,90.,-2)
540    CONTINUE
       CALL SYMB(.1,6.5,.1,11,.0,-2)
       DO 550 I=0,10
       XI=.5+(I*1.4)
       CALL SYMB(XI,6.5,.1,13,.0,-2)
550    CONTINUE
       CALL SYMB(14.8,6.5,.1,11,.0,-2)
       DO 560 I=0,FTIC
       YI=6.5-(I*3./FTIC)
       CALL SYMB(14.5,YI,.1,13,90.,-2)
560    CONTINUE
       CALL NUMB(7.375,3.3,.1,50.,0.,-1)
       CALL NUMB(.4,3.55,.1,0.,90.,-1)
       DO 570 I=1,4
       YTIC=I*.6/RSCALE
       YI=3.225+(I*.6)
       CALL NUMB(.4,YI,.1,YTIC,90.,3)
570    CONTINUE
```

PROGRAM DS2 (CONT)

```
      IY(1)=18
      IY(2)=2HPA
      IY(3)=2HDI
      IY(4)=2HUS
      IY(5)=2H O
      IY(6)=2HF
      IY(7)=2HCE
      IY(8)=2HNT
      IY(9)=2HRO
      IY(10)=2HID
      CALL SYMB(.2,3.9,.12,IY(1),90.,1)
      CALL PLOT(.5,6.5,3)
      DO 580 I=1,8
      YI=6.5+(I*.375)
      CALL SYMB(.5,YI,.1,13.,90.,-2)
  580 CONTINUE
      DO 590 I=0,10
      XI=.5+(I*1.4)
      CALL SYMB(XI,9.5,.1,13.,0.,-2)
  590 CONTINUE
      DO 600 I=0,8
      YI=9.5-(I*.375)
      CALL SYMB(14.5,YI,.1,13.,90.,-2)
  600 CONTINUE
      IY(1)=14
      IY(2)=2HBA
      IY(3)=2HLA
      IY(4)=2HNC
      IY(5)=2HE
      IY(6)=2HAN
      IY(7)=2HGL
      IY(8)=2HE
      CALL NUMB(7.375,6.3,.1,50.,0.,-1)
      CALL NUMB(.4,6.55,.1,0.,90.,-1)
      DO 610 I=1,4
      YTIC=90*I
      YI=6.38+(I*.75)
      CALL NUMB(.4,YI,.1,YTIC,90.,-1)
  610 CONTINUE
      CALL SYMB(.2,7.3,.12,IY(1),90.,1)
        CALL PLOT(.5,.5,-3)
C     THE REMAINING CALLS FOR PLOTTING DATA WILL GO HERE
      DO 730 I=1,3
  700  COUNT=0
       ISTAT=1
        CALL PLOT(.14,YHT(1),3)
  710  EX=ECC(ISTAT)+.0015
       AX=EX*EX*SIN(I(I) EX)*100
       AXMIN=EX*EX*SIN(T(3) EX)*200
       IF ((AX-AXMIN) .GT. BAL(ISTAT)) GOTO 720
        IF (I .EQ. 1) COUNT=1
       TCT(ISTAT,I)=TCT(ISTAT,I)+1
        YHT(ISTAT)=YHT(ISTAT)+(AX*B(I)*ALE EX)
       BAL(ISTAT)=BAL(ISTAT)-AX
       ECC(ISTAT)=ECC(ISTAT)+.003
  720   X=ISTAT*.14
        CALL PLOT(X,YHT(ISTAT),2)
       ISTAT=ISTAT+1
       IF (ISTAT .LT. 101) GOTO 710
       IF (COUNT .GT. 0)   GOTO 700
  730 CONTINUE
        CALL PLOT(0.,0.,3)
```

```
        WRITE(6,17)
        LINE=5
        DO 800 I=1,100
        LINE=LINE+1
        IF (LINE .LT. 5) GOTO 750
        WRITE(6,13)
        LINE=0
  750     WRITE(6,18)I,TCT(I,1),TCT(I,2),TCT(I,3),ATHETA(I)
        RBAR(I)=RBAR(I)*RSCALE
        ATHETA(I)=ATHETA(I) 120.
        BWGHT(I)=BWGHT(I)*BSCALE
         YDATA(I,1)=BWGHT(I)
         YDATA(I,2)=RBAR(I)
         YDATA(I,3)=ATHETA(I)
  800   CONTINUE
        DO 1000 I=1,3
         CALL PLOT(.14,YDATA(1,I),3)
         DO 900 ISTAT=1,100
          X=ISTAT*.14
          CALL PLOT(X,YDATA(ISTAT,I),2)
  900    CONTINUE
         IF (I .EQ. 1) CALL PLOT(0.,3.,-3)
         IF (I .EQ. 2) CALL PLOT(0.,3.,-3)
 1000    CONTINUE
         CALL URITE
         RETURN
         END
        END$
```

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EN

DAT